Issued January 27, 1913.

U. S. DEPARTMENT OF AGRICULTURE,

FOREST SERVICE—BULLETIN 122.

HENRY S. GRAVES, Forester.

FOREST PRODUCTS LABORATORY SERIES.

MECHANICAL PROPERTIES OF WESTERN LARCH.

BY

O. P. M. GOSS,

Engineer in Forest Products.

WASHINGTON:

GOVERNMENT PRINTING OFFICE.

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LETTER OF TRANSMITTAL.

U. S. DEPARTMENT OF AGRICULTURE,
FOREST SERVICE,
Washington, August 26, 1912.

SIR: I have the honor to transmit herewith a manuscript entitled "Mechanical Properties of Western Larch," by O. P. M. Goss, engineer in forest products, and to recommend its publication as Bulletin 122 of the Forest Service.

Very respectfully,

HENRY S. GRAVES,
Forester.

Hon. JAMES WILSON,
Secretary of Agriculture.

CONTENTS.

ILLUSTRATIONS.

PLATES.

TEXT FIGURES.

MECHANICAL PROPERTIES OF WESTERN LARCH.

INTRODUCTION.

This bulletin presents the results of a series of tests to determine the mechanical and physical properties of western larch, and describes the various structural uses of the wood. Western larch is at present but little used, and knowledge of its properties is very limited.

The tests were made at the Seattle laboratory of the Forest Service, conducted in cooperation with the University of Washington, on material donated by the Western Pine Manufacturers' Association. The trees were selected by members of the Forest Service on the holdings of the Phoenix Lumber Co. in Stevens County, Wash. The logs were sawed at Spokane, whence free transportation to Seattle was furnished by the Northern Pacific Railroad.

Western larch (*Larix occidentalis*) is more commonly known as larch or tamarack. It occurs throughout the basin of the Columbia River from southern British Columbia to the western slope of the Continental Divide in Montana, and to the eastern slope of the Cascade Mountains in Oregon. The best stands of larch timber are found in northern Idaho, northeastern Washington, and northwestern Montana. Western larch is usually associated with other species, but sometimes grows in pure stands.

The annual layers of growth, or annual rings, show distinctly in a cross section. Each year's growth consists of a dark and a light colored band. The number of rings per radial inch in the material tested varied from 11 to 60. The dark portion of an annual ring, called the summerwood, is much harder and stronger than the light-colored and softer springwood. Plates I, II, and III show the wood in transverse, radial, and tangential sections. The wood consists chiefly of fibers or cells running lengthwise with the trunk. At right angles to these fibers are the pith rays, running in radial planes. Resin ducts also occur, confined generally to the summerwood. The heartwood is reddish brown in color, and the sapwood yellowish white. The latter runs from ½ to 1½ inches in thickness for trees up to 3 feet in diameter. The grain of the wood is usually straight. Knots are generally sound and not over 1½ inches in diameter; they are common, and frequently occur in groups or clusters.

MATERIAL TESTED.

The test material was divided into two classes:

1. Bridge stringers and car sills containing defects commonly found in timber purchased on the market, such as knots, checks, and shakes. The bridge stringers were of two sizes—8 by 12 inches by 16 feet, and 8 by 16 inches by 16 feet. The car sills were 5 by 8 inches by 16 feet. The purpose of the tests was to secure strength values for use in design, to determine the influence of seasoning and of defects on strength, and to compare the efficiency of grading rules and specifications.

2. Small, clear, straight-grained pieces cut from the uninjured portions of the large beams. These were tested to determine the effect upon strength of rate of growth, weight, and moisture. The study of these relations requires clear material, free from the defects common in market material.

METHODS OF TEST.[1]

BENDING.

In the bending tests the specimens were supported near the ends, and the load applied either at the center of the span or at two points, each located at one-third of the length of the span from the end supports. The first method, called "center loading," was used in testing the small pieces, 2 by 2 by 30 inches; the second method, called "third-point loading," was used in testing the stringers and sills. The latter method reproduced closely the conditions to which a beam is subjected in structural work. The tests were made with a universal testing machine, and the load was gradually and continuously applied until the specimen failed. The amount of bending or deflection was noted at regular increments of load. Four factors were calculated from the data derived from each bending test, all in terms of pounds per square inch:

(*a*) *Fiber stress at elastic limit.*—This is the greatest stress that can occur in a beam loaded with an external load from which it will recover without permanent deflection.

(*b*) *Modulus of rupture.*—This is the greatest computed stress in a beam loaded with a breaking load.

(*c*) *Modulus of elasticity.*—This is a factor computed from the relation between load and deflection within the elastic limit, and represents the stiffness of the wood fiber.

(*d*) *Longitudinal shear.*—This is the stress tending to split the beam lengthwise along its neutral plane[2] when under maximum load.

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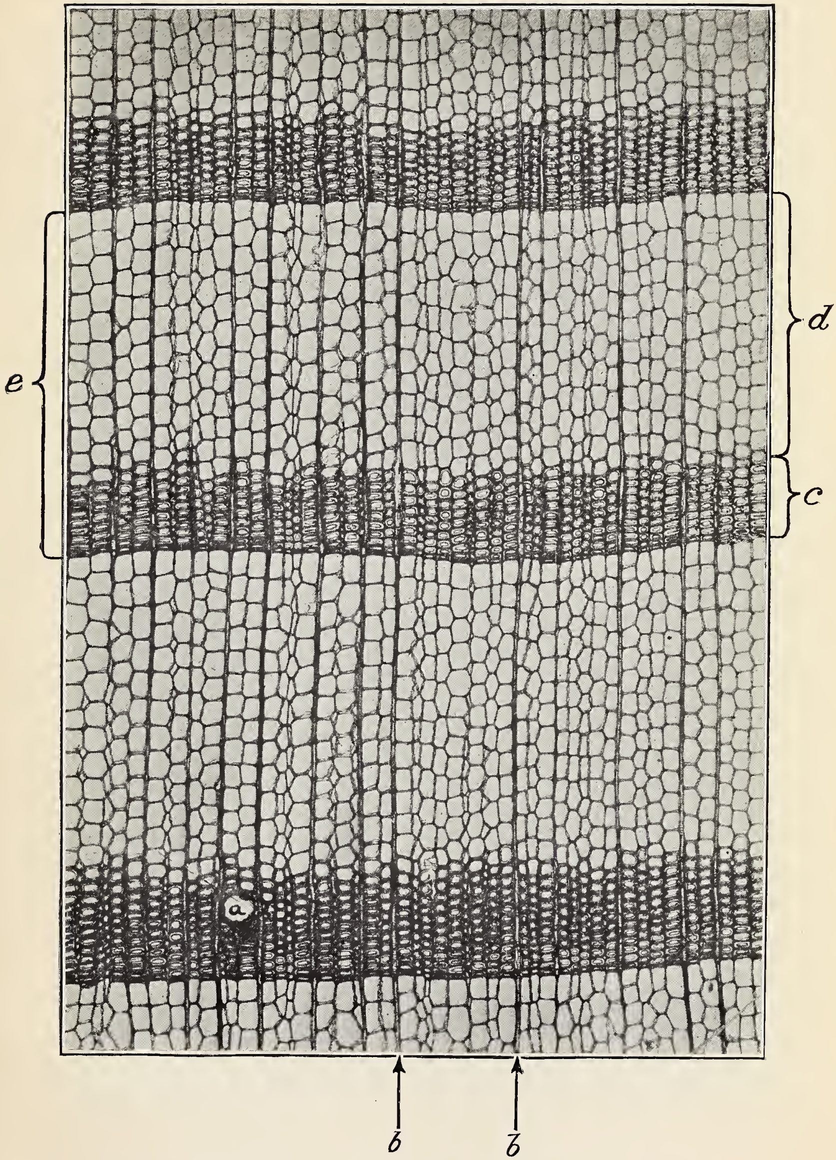
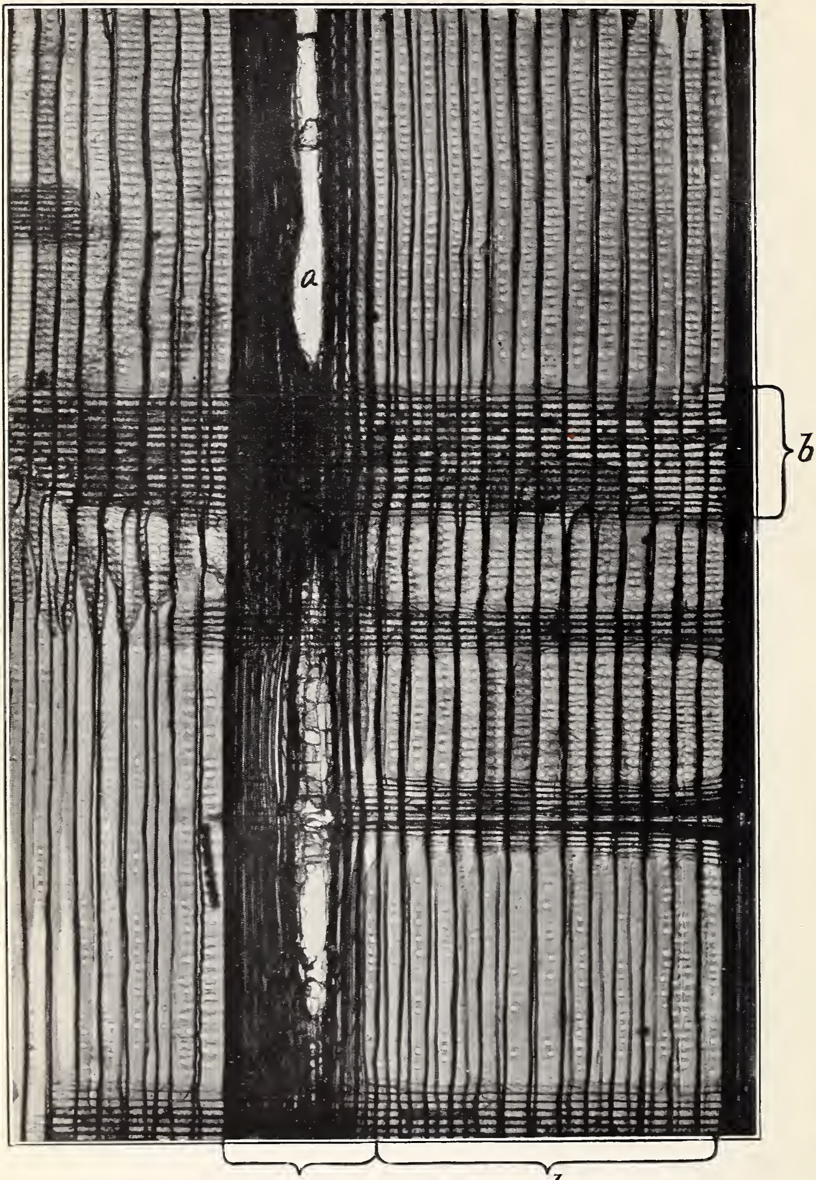
[1] The methods which were used in testing western larch are in accordance with Forest Service standards, and are fully described in Circular 38, Instructions to Engineers of Timber Tests, Revised. Forest Service Bulletin 88, Properties and Uses of Douglas Fir, by McGarvey Cline and J. B. Knapp, and Bulletin 108, Tests of Structural Timbers, by McGarvey Cline and A. L. Heim, also briefly describe the tests commonly made with illustrations of the testing machines.

[2] Plane between upper and lower halves when beam is horizontal.



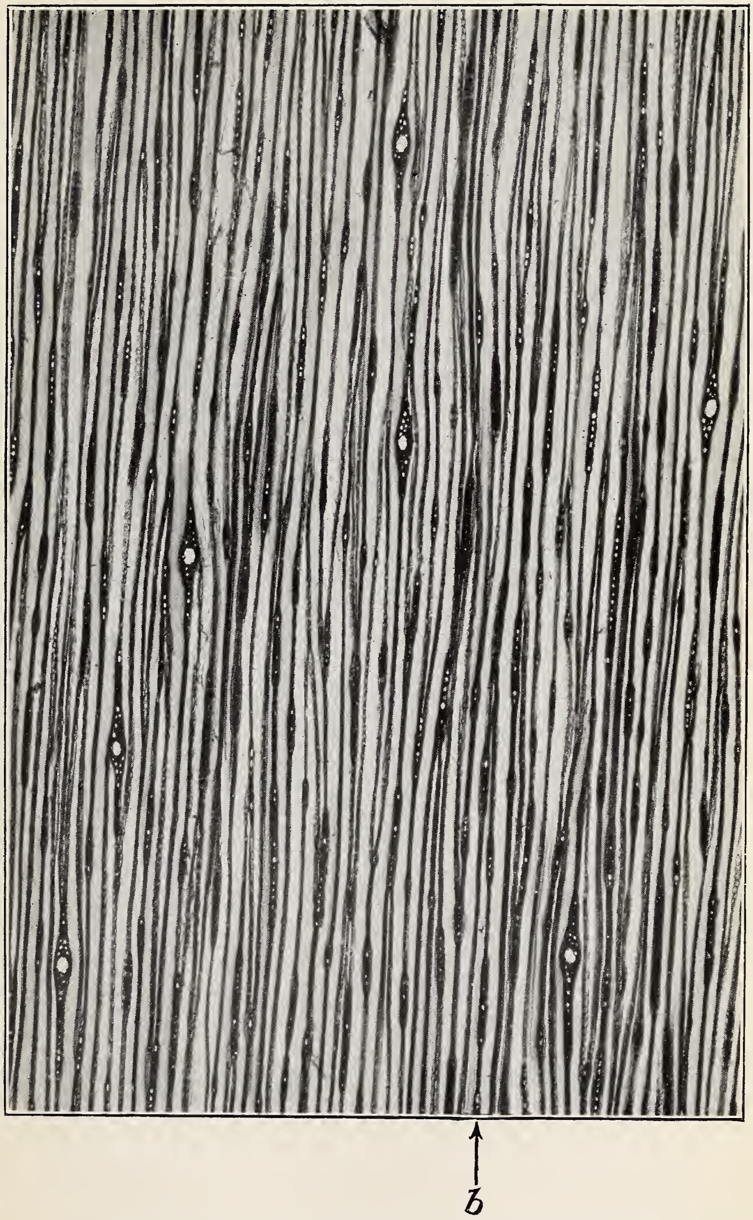
TRANSVERSE SECTION OF WESTERN LARCH MAGNIFIED 50 TIMES.

a, resin duct; *b*, pith ray; *c*, summerwood; *d*, springwood; *e*, annual ring.



RADIAL SECTION OF WESTERN LARCH MAGNIFIED 50 TIMES.

a, resin duct; *b*, pith ray; *c*, summerwood; *d*, springwood.



TANGENTIAL SECTION OF WESTERN LARCH MAGNIFIED 50 TIMES.

b, pith ray.

COMPRESSION PARALLEL TO GRAIN.

Two sizes of specimens were used, 6 by 6 by 24 inches, and 2 by 2 by 8 inches. The specimens were set upright on the platform of the testing machine and crushed endwise. Observations of amount of load and deflection, or compression, were made as in the bending tests. From the data were calculated in pounds per square inch:

(*a*) Compressive strength at elastic limit.

(*b*) Crushing strength at maximum load.

(*c*) Modulus of elasticity.

COMPRESSION PERPENDICULAR TO GRAIN.

The specimens consisted of large blocks 8 by 16 by 24 inches, and 8 by 12 by 24 inches, and of smaller blocks 6 by 6 by 24 inches, 5 by 8 by 20 inches, and 4 by 4 by 16 inches. The tests were made by laying each block on its side on the platform of the machine, and applying pressure to an iron plate resting on the block's upper sides. The test corresponds to the action of a rail on a crosstie, or a floor joist on a supporting beam. Readings of the load and the corresponding deflection or crushing were taken up to and slightly beyond the elastic limit. From these data the compressive strength at elastic limit in pounds per square inch was calculated.

SHEARING.

These tests were made on small, clear blocks with a projecting lip 2 by 3 inches in section. The blocks were held firmly, and the lip sheared off parallel to the grain. The load required to shear off the lip was calculated in pounds per square inch.

SHRINKAGE.

Shrinkage tests were made on large beams and car sills and on small specimens. Weights and measurements were taken from time to time on the large timbers to determine their rate of seasoning and the resulting shrinkage.

Small, clear specimens 3 by 3 by 3 inches were weighed and measured periodically while passing from the green to the oven-dry condition. After being thoroughly dried they were subsequently allowed to absorb moisture from the air, and records were secured showing the resultant increase in size.

MOISTURE DETERMINATIONS.

Sections approximately 1 inch thick were cut from all test pieces as soon as possible after testing, and, after weighing, were dried to constant weight at 100° C. The difference between the original and dry weights divided by the dry weight gives the per cent of moisture

in the pieces at the time of test. In some cases the sections were cut into a number of pieces before drying, and each piece weighed separately. In this way it was possible to find the distribution of moisture throughout the section.

GENERAL TEST OBSERVATIONS.

All test pieces were weighed and measured and the number of rings counted on a radial line. Sketches were made showing failures and the size and location of knots, checks, and shakes. The proportion and location of sapwood was also noted.

AVERAGE VALUES.[1]

Table 1 shows average strength values determined from tests made on structural forms, and on small, clear sticks cut from the large pieces after test. The various species represented are those most commonly used in construction work. The longleaf pine timbers tested were partially seasoned, and consequently the strength values given are slightly greater than would be found in thoroughly green wood. The test material from all other species was thoroughly green.

Table 2 gives the average strength values obtained from tests on western larch bridge stringers and car sills and from small pieces cut from them. Values for both green and air-seasoned material are shown, as well as the ratios of the values for air-seasoned timber to the corresponding values for green timber.

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[1] In the following summaries and figures the weight per cubic foot is based on the volume of the specimen when tested. If the dry weight per cubic foot is calculated for a green timber and, later, this timber is allowed to air season, and a second dry weight per cubic foot computed, these two determinations will be different. An error is introduced due to the shrinkage which occurs in the timber in passing from the green to the air-seasoned condition. It is, therefore, necessary in comparing the dry weight per cubic foot calculated from green and air-seasoned timbers to consider the shrinkage which occurs in seasoning. On page 31 of this bulletin shrinkage is discussed, and figures are given which permit the dry weights of wood calculated from pieces in various conditions of moisture to be reduced to the same basis.

In all diagrams the numbers near the points through which the curves are drawn indicate the number of tests averaged for the respective points.

TABLE 1.—*Average strength values for different species; green structural timbers and small pieces without defects.*

Species.	Weight per cubic foot, oven dry.	Rings per inch.	Bending.					Compression parallel to grain.			Compression perpendicular to grain.	Shear.
			Number of tests.	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.	Horizontal shear.[1]	Compressive strength at elastic limit.	Crushing strength at maximum load.	Modulus of elasticity.	Compressive strength at elastic limit.	Shearing strength.
	Pounds.			*Pounds per sq. in.*	*Pounds per sq. in.*	*1,000 lbs. per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*1,000 lbs. per sq. in.*	*Pounds per sq. in.*	*Pounds per sq. in.*
Longleaf pine:												
Structural sizes	35	13.8	17	3,734	6,140	1,463	353	3,480	4,800		568	
Small specimens			15	4,950	9,070	1,540			4,400			973
Ratio				.75	.68	.95			1.09			
Douglas fir:												
Structural sizes	28	11.0	191	3,968	5,983	1,517	166	2,770	3,495	1,414	570	
Small specimens			568	5,227	8,280	1,597		3,500	4,030	1,925		765
Ratio				.76	.72	.95		.79	.87	.74		
Shortleaf pine:												
Structural sizes	30	12.1	48	3,237	5,548	1,473	332	2,460	3,435	1,548	351	
Small specimens			254	4,350	7,710	1,395			3,570		400	704
Ratio				.74	.72	1.06			.96		.88	
Western larch:												
Structural sizes	28	24.3	62	3,325	4,918	1,300	288	2,674	3,509	1,575	456	
Small specimens			189	4,274	7,251	1,310		3,026	3,696	1,545		700
Ratio				.78	.68	.99		.88	.95	1.02		
Loblolly pine:												
Structural sizes	31	5.9	111	3,040	5,084	1,387	335	2,050	2,940	548	500	
Small specimens			44	4,100	7,870	1,440			3,240			630
Ratio				.74	.65	.96			.91			
Tamarack:												
Structural sizes	30	14.0	30	2,813	4,556	1,220	261	2,400	3,230	1,373		
Small specimens			82	3,875	6,820	1,141			3,190			668
Ratio				.73	.67	1.07			1.01			
Western hemlock:												
Structural sizes	27	15.6	39	3,516	5,295	1,445	288	2,910	3,400	1,619	465	
Small specimens			52	4,406	7,294	1,428		2,938	3,392	1,737		630
Ratio				.80	.73	1.01		.99	1.00	.93		
Redwood:												
Structural sizes	22	18.8	28	3,760	4,472	1,042	302	3,194	3,882	1,240	434	
Small specimens			157	4,750	6,980	1,061		3,490	3,980	1,222	569	742
Ratio				.79	.64	.98		.92	.98	1.01	.76	
Norway pine:												
Structural sizes	25	13.7	49	2,492	3,864	1,133	232	2,065	2,555	1,002		
Small specimens			133	2,808	5,173	960			2,504			589
Ratio				.89	.75	1.18			1.02			

[1] Only those pieces which failed first by horizontal shear are included in this column.

TABLE 2.—*Average strength values for green and air-seasoned western larch in structural sizes and for small pieces without defects.*

GREEN MATERIAL.

Cross section.	Bending.							Compression parallel to grain.						Compression perpendicular to grain.			Shear.		
	Number of tests.	Rings per inch.	Moisture.	Weight per cubic foot, oven dry.	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.	Size of specimen.	Number of tests.	Moisture.	Compressive strength at elastic limit.	Crushing strength at maximum load.	Modulus of elasticity.	Number of tests.	Moisture.	Compressive strength at elastic limit.	Number of tests.	Moisture.	Shearing strength.
Inches.			*Per cent.*	*Pounds.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*1,000 lbs. per sq. in.*	*Inches.*		*Per cent.*	*Pounds per sq. in.*	*Pounds per sq. in.*	*1,000 lbs. per sq. in.*		*Per cent.*	*Pounds per sq. in.*		*Per cent.*	*Pounds per sq. in.*
8 x 16...	32	25.3	51.0	27.9	3,276	4,600	1,272	6 x 6 x 24	107	49.1	2,674	3,509	1,575	125	48.6	456	179	40.7	700
8 x 12...	30	23.2	50.3	28.8	3,376	5,253	1,331	2 x 2 x 8	491	50.6	3,026	3,696	1,545	....	....	....	....	....	....
5 x 8...	14	25.6	56.0	30.5	3,528	5,331	1,432	....	....	....	....	....	....	....	....	....	....	....	....
2 x 2...	189	26.2	46.2	28.6	4,274	7,251	1,310	....	....	....	....	....	....	....	....	....	....	....	....
AIR-SEASONED MATERIAL.																			
8 x 16...	24	22.1	18.3	28.9	3,290	5,440	1,408	6 x 6 x 24	193	15.4	3,506	5,750	1,752	68	16.3	583	193	15.0	905
8 x 12...	30	23.3	17.8	29.5	3,631	6,118	1,549	2 x 2 x 8	268	14.8	4,174	5,937	1,630	....	....	....	....	....	....
5 x 8...	13	28.8	13.4	30.4	4,730	6,559	1,620	....	....	....	....	....	....	....	....	....	....	....	....
2 x 2...	239	26.8	16.0	30.4	5,886	1,230	1,565	....	....	....	....	....	....	....	....	....	....	....	....
RATIO—AIR SEASONED TO GREEN.																			
8 x 16...	....	....	....	....	1.00	1.18	1.11	6 x 6 x 24	....	....	1.31	1.64	1.11	....	....	1.28	....	....	1.29
8 x 12...	....	....	....	....	1.08	1.16	1.16	2 x 2 x 8	....	....	1.38	1.61	1.05	....	....	....	....	....	....
5 x 8...	....	....	....	....	1.34	1.23	1.13	....	....	....	....	....	....	....	....	....	....	....	....
2 x 2...	....	....	....	....	1.38	1.41	1.19	....	....	....	....	....	....	....	....	....	....	....	....

The results of the tests on both large and small pieces are shown in more detail in Tables 11 to 13, Appendix. The relation between the size and unit strength of green pieces is shown graphically in figure 1. All test results used in this figure were secured from pieces in which the failure was not influenced by defects, and which did not fail first in longitudinal shear.

VARIABILITY OF RESULTS.

Table 3 shows to what extent the results from individual tests vary from the average values. The column at the left indicates the variation above and below the average values. The per cent of the total number of tests falling within any given range is shown in the other columns. The results of all tests made on green wood were used in this analysis.

The variation from the average values is greatest for the modulus of rupture of large beams and for compressive strength at elastic limit for large specimens tested in compression perpendicular to grain. It may be concluded therefore that the modulus of rupture is readily influenced by disturbing factors, such as ordinary defects. The great variation in the compressive strength at elastic limit is due to the variable character of the grain in the different blocks. Some blocks had edge grain, some flat grain, and some intermediate grain. Edge grain wood (radial surface) when tested in side bearing is considerably stronger than similar wood tested with the grain flat (tangential surface). The results of these tests show what may be expected in the case of large timbers in which the position of the grain or rings in the bearing surface varies, according to the way the beams are cut from the logs.

Least variation from the average values is found in the small beam tests and in tests in compression parallel to the grain.

TABLE 3.—*Variation of the different strength factors from their average values.*

Kind of test	Bending.						Compression parallel to grain.		Compression perpendicular to grain.	Shearing.
Kind of specimen	Stringers.			Small, clear.			Large ordinary defects.	Small, clear.	Large, clear.	Small, clear.
Size of specimen	8 x 16 inches and 8 x 12 inches, all 16 feet long.			2 x 2 x 30 inches.			6 x 6 x 24 inches.	2 x 2 x 8 inches.	8 x 16 x 24 inches, 8 x 12 x 24 inches, 6 x 6 x 24 inches, 5 x 8 x 20 inches, and 4 x 4 x 16 inches.	2 x 3 inches.
Strength factors	Fiber stress at elastic limit.	Modulus of rupture	Modulus of elasticity.	Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.	Crushing strength at maximum load.	Crushing strength at maximum load.	Compressive strength at elastic limit.	Shearing strength
Number of tests	62	62	62	189	189	189	157	491	125	179
Average values, pounds per square inch	3,325	4,918	1,300,000	4,274	7,251	1,310,000	3,365	3,696	456	700
Per cent of total number of tests that fell above the average	53	53	45	50	49	48	50	48	36	49
Per cent of total number of tests that fell below the average	47	47	55	50	51	52	50	52	64	51
Distribution of individual tests with regard to the average—in per cent of total number of tests:										
Between 160 and 165 per cent of the average									1	
Between 155 and 160 per cent of the average	2								0	
Between 150 and 155 per cent of the average	0								1	
Between 145 and 150 per cent of the average	1	5				1			2	
Between 140 and 145 per cent of the average	2	1				1			1	1
Between 135 and 140 per cent of the average	2	1	3	1		2		1	2	2
Between 130 and 135 per cent of the average	4	2	7	1	1	4		2	1	0
Between 125 and 130 per cent of the average	7	8	2	3	1	4	2	2	2	2
Between 120 and 125 per cent of the average	6	8	7	5	4	4	4	5	1	4

Between 115 and 120 per cent of the average	4	6	6	6	4	6	12	5	12	5
Between 110 and 115 per cent of the average	11	9	8	16	9	5	9	8	1	8
Between 105 and 110 per cent of the average	4	6	10	6	16	10	13	11	9	10
Between 100 and 105 per cent of the average	10	7	2	12	14	11	10	14	3	17
Between 95 and 100 per cent of the average	5	4	10	10	14	8	11	12	24	14
Between 90 and 95 per cent of the average	7	13	13	13	17	13	14	15	5	15
Between 85 and 90 per cent of the average	4	5	11	11	11	10	13	10	15	10
Between 80 and 85 per cent of the average	8	6	4	6	5	8	4	8	1	6
Between 75 and 80 per cent of the average	3	3	5	4	2	4	3	5	12	2
Between 70 and 75 per cent of the average	4	2	7	4	1	4	3	1	2	1
Between 65 and 70 per cent of the average	5	1	1	1	0	4	2	1	3	1
Between 60 and 65 per cent of the average	6	4	1	1	1	1	....	....	1	1
Between 55 and 60 per cent of the average	5	5	3	....	....	....	....	....	1	1
Between 50 and 55 per cent of the average	....	4	....	....	....	....	....	....	1	0
Between 45 and 50 per cent of the average	....	....	....	....	....	....	....	....	....	1
Between 40 and 45 per cent of the average	....	....	....	....	....	....	....	....	....	....

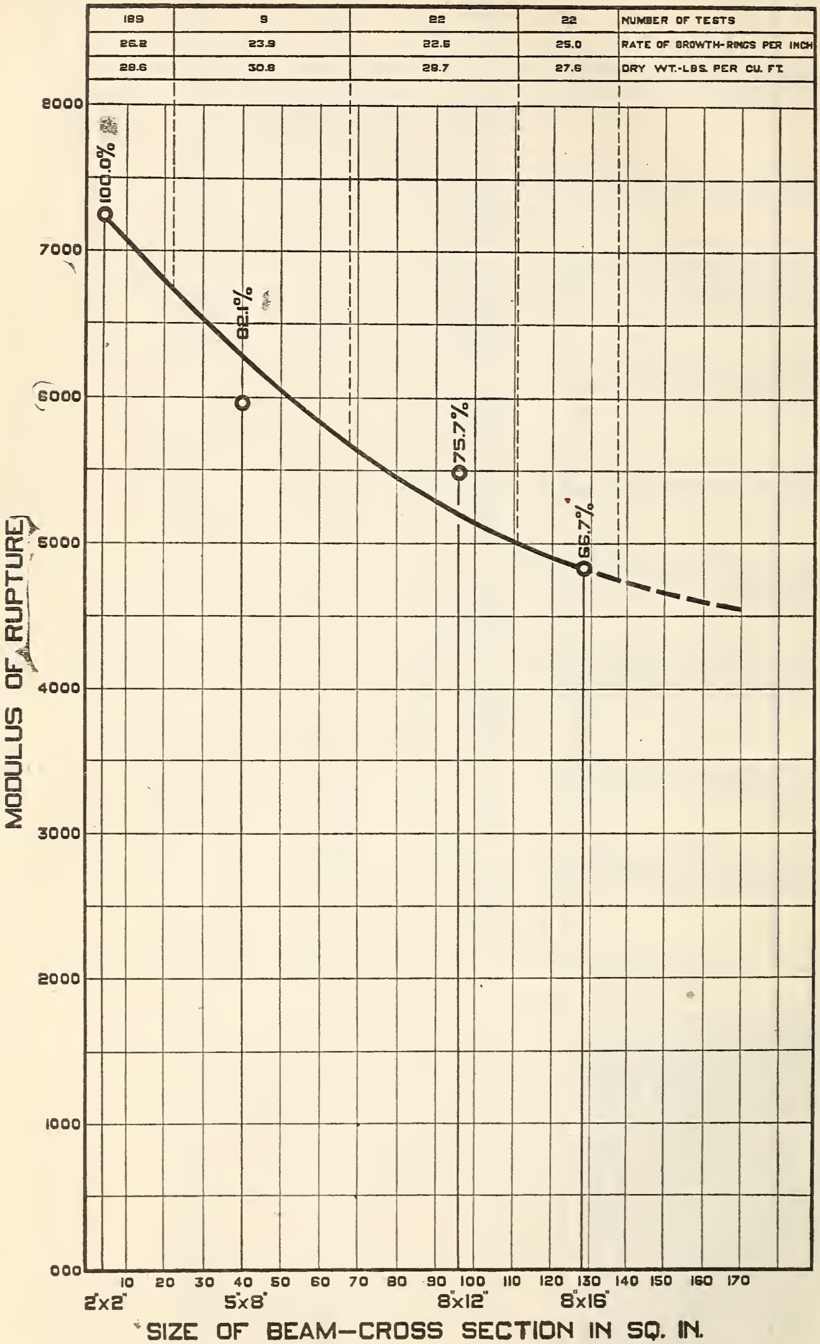

FIG. 1.—Modulus of rupture for green western larch beams of different sizes.

RELATION BETWEEN STRENGTH VALUES.

In figure 2 the strength values, dry weight, and rate of growth are plotted for individual tests for both green and air-seasoned beams.

The diagram was made by first plotting the values for modulus of rupture, arranged from the highest to the lowest, beginning with the highest value on the left at the top of the figure. The other values for the same beams were then plotted in the same vertical lines. Points for green beams are joined with broken lines, and points for air-seasoned beams, with solid lines. The four different grades used for structural timber by the West Coast Lumber Manufacturers' Association are designated by the kind of circle used in plotting the points. (See legend on the figure.) The fiber stress at elastic limit and the modulus of elasticity decrease in an irregular way with the modulus of rupture. In the case of beams showing low values for modulus of rupture, there is comparatively little difference between this factor and fiber stress at elastic limit.

Figure 3 was made by first plotting the values for modulus of rupture of the green stringers from the highest to the lowest, as in figure 2. Values representing other properties of the stringers and the strength properties of the small pieces cut from them were also plotted. The points in any one vertical line represent values for a single beam, or average values of pieces cut from that beam. Values for the modulus of rupture of small pieces shown at the top of the figure represent the bending strength of the wood free from all defects. A comparison of the modulus of rupture of the stringers with that of the small pieces shows that as the stringers decrease in strength the small pieces cut from them also decrease, but not in the same degree. The crushing strength of small pieces decreases in practically the same manner as the modulus of rupture of the small, clear beams. These comparisons indicate that the greater range of strength in the stringers is due to other factors than the quality of the clear wood; that is, to defects, such as knots, shakes, or checks. Values for modulus of elasticity in both stringers and small pieces are very close together, indicating that knots, checks, and shakes have little effect on stiffness. Values for shearing strength and compressive strength perpendicular to grain show little tendency to change as the modulus of rupture of the large beams decreases. This is to be expected from the nature of these tests.

Table 4 shows the shearing stress developed in green and seasoned stringers failing in longitudinal shear, and in small, clear shear specimens. The shearing strength in structural sizes is much less than in the small pieces. The ratio of the shearing strength of the stringers to that of the small blocks is higher in the green (0.45) than in the seasoned material (0.38). This is to be expected, since timbers usually check during seasoning, and this reduces the shear-resisting area (neutral plane).

TABLE 4.—*Comparison of horizontal shear developed in green and seasoned western larch stringers to the shearing strength in small, clear blocks.*

Seasoning condition.	Bending tests.						Shear parallel to grain.		
	Number of tests.	Rings per inch.	Moisture.	Weight per cubic foot.		Maximum horizontal shear.	Number of tests.	Maximum shearing strength.	Ratio, large to small.
				As tested.	Oven dry.				
			Per cent.	*Pounds.*	*Pounds.*	*Pounds per square inch.*		*Pounds per square inch.*	
Green:									
Maximum	1	30.8	66.8	52.4	33.2	414	1	1,000	
Average	12	23.8	52.2	45.0	29.5	317	179	700	0.45
Minimum	1	18.6	38.0	36.9	25.7	190	1	336	
Air seasoned:									
Maximum	1	30.9	21.7	46.7	38.8	449	1	1,534	
Average	20	22.8	[1] 18.7	36.4	[1] 29.9	344	193	905	.38
Minimum	1	15.4	16.5	29.5	25.3	150	1	485	

[1] Based on 18 tests.

RELATION BETWEEN MECHANICAL PROPERTIES AND PHYSICAL CHARACTERISTICS.

The wide range in the strength of western larch timber suggests a study of the relation of defects, rate of growth, and weight to the mechanical properties. A knowledge of the relation of such characteristics to the various strength properties is of help in adjusting grading rules and specifications so that their application will divide timber into groups of comparatively uniform strength.

DEFECTS.[1]

Knots, shakes, checks, cross grain, and sap are common defects in western larch.

KNOTS.

Knots are classified with respect to their size and condition. Pin knots [2] are ½ inch or less in diameter; small knots, ½ inch to 1½ inches; and large knots, over 1½ inches. With respect to their condition, such terms are used as "sound," "rotten," "loose," and "encased" (surrounded entirely or in part by bark or pitch). Pith knots are sound knots with pith holes not over ¼ inch in diameter.

The effect of groups of knots common in western larch depends (1) on the location of the groups in the piece with reference to the way the stick is to be used, (2) on the disturbance caused in the grain of the wood, and (3) on the size of the knots in the group. A group of knots near the center of a beam close to the lower side would have considerable influence on its strength, while a similar group near the end would probably have no weakening effect. Practically all the knots in the test material were sound. The majority were pin knots, or small knots. A comparatively small knot situated near enough

[1] Defects in timber are more fully discussed in Forest Service Bulletin 108, Tests of Structural Timbers.

[2] This class of knots is not recognized in the definitions on p. 36.

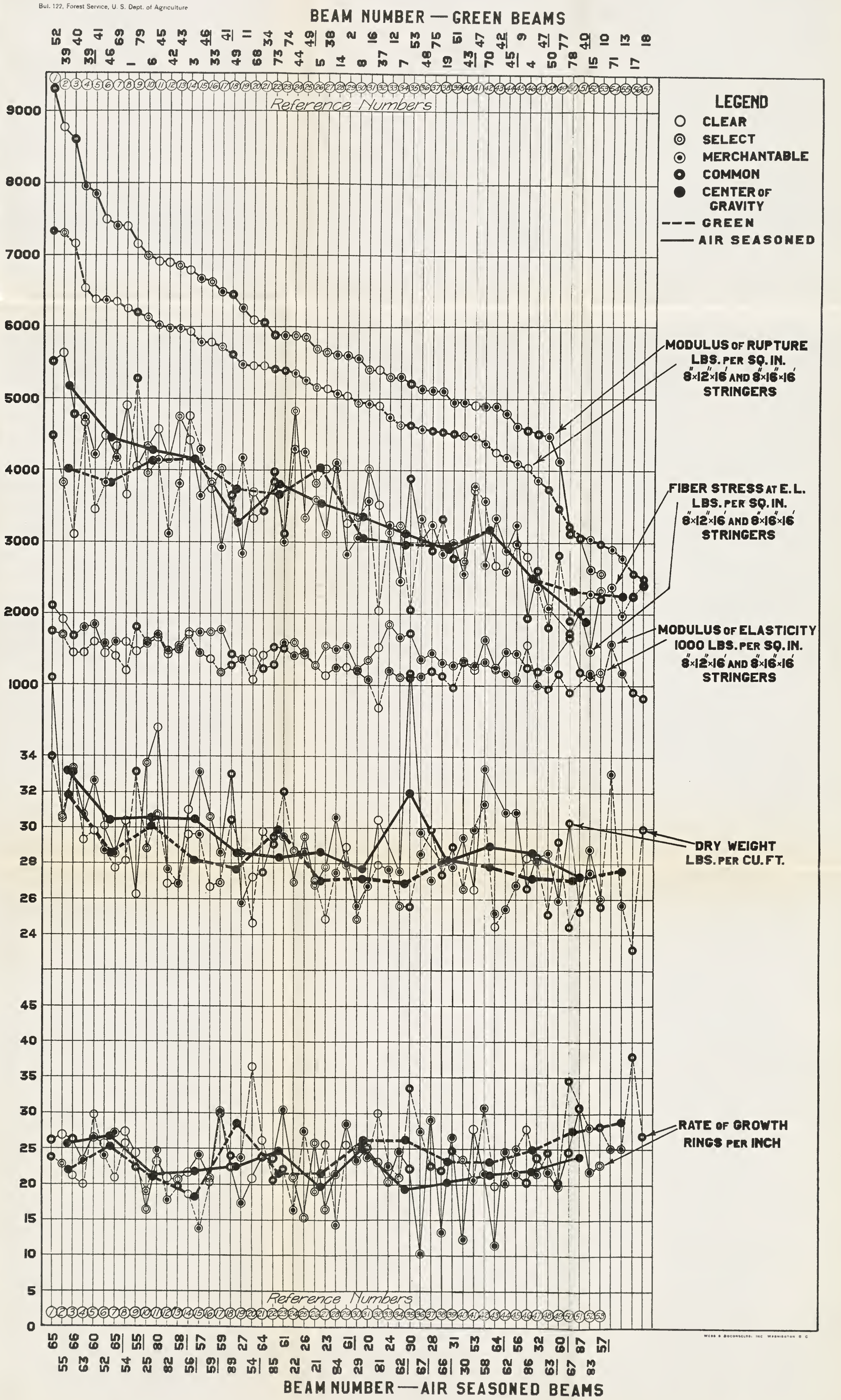

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FIG. 2.—RELATION BETWEEN MODULUS OF RUPTURE AND OTHER TEST VALUES FOR BOTH GREEN AND AIR-SEASONED BRIDGE STRINGERS.

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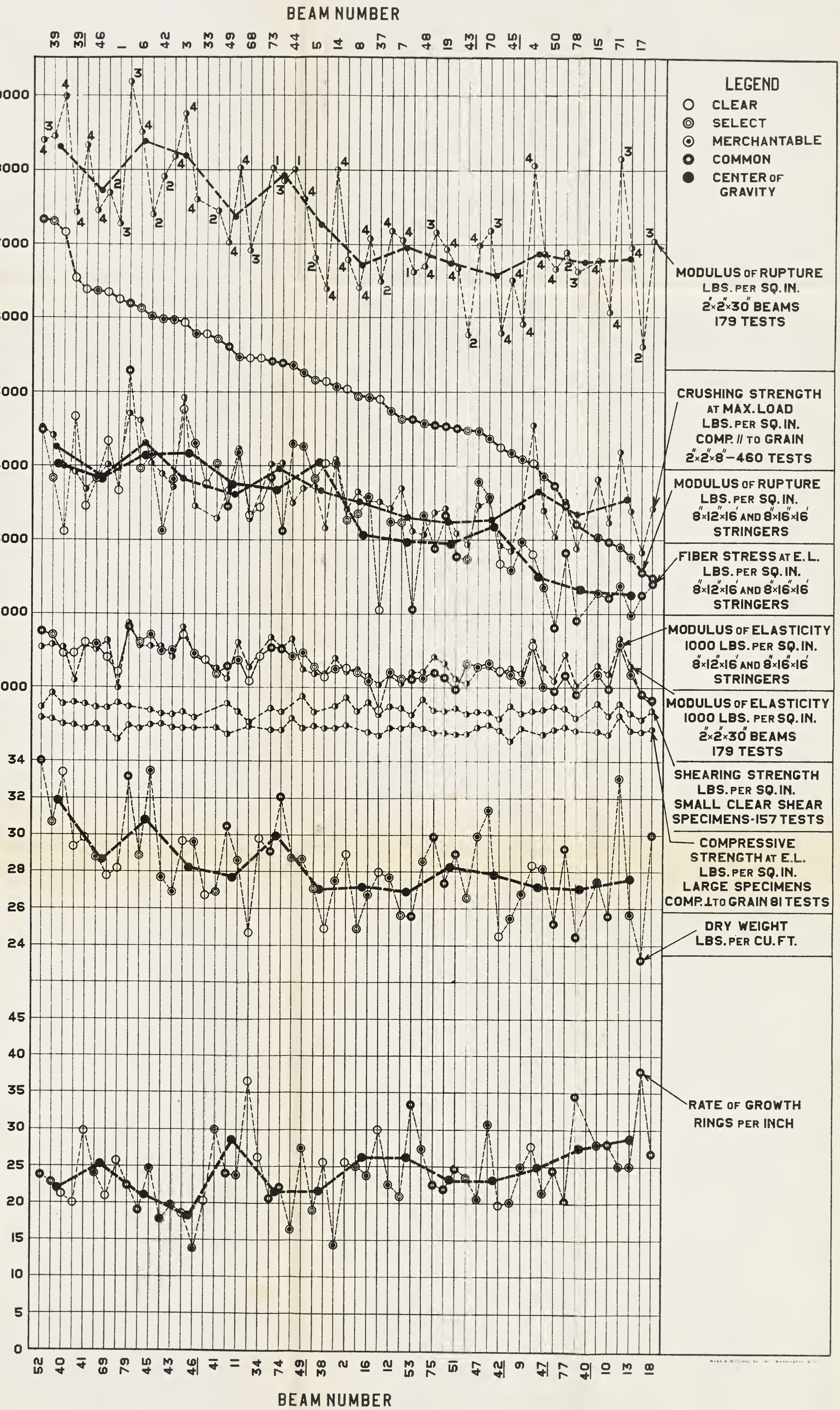


FIG. 3.—RELATION OF MODULUS OF RUPTURE OF STRINGERS TO OTHER TEST VALUES FOR BOTH LARGE AND SMALL PIECES

to the lower edge of a beam to deflect the grain beyond the edge is more harmful than a larger knot so placed as to allow the grain to continue. The nearer a knot is to the neutral plane[1] the less it weakens the stick. In some cases knots near the neutral plane may act as pins and strengthen a beam against splitting lengthwise in longitudinal shear. Knots at the top of a beam are not as weakening as those at the bottom.

In order to study the influence of knots on the strength of structural timbers a series of tests was made some years ago by the Forest Service on loblolly pine beams from the Southwest, and more recently on Douglas fir beams from the Northwest. In these tests the beams were divided into three groups, according to the location of knots. Figure 4 shows the basis of classification. Sticks with knots in volume 1, which comprises the middle half of the beam one-fourth of the height up from the bottom, form group 1; sticks with knots in volume 2, but having volume 1 free from defects, form group 2; all other sticks, which consist of those having both volume 1 and vol-

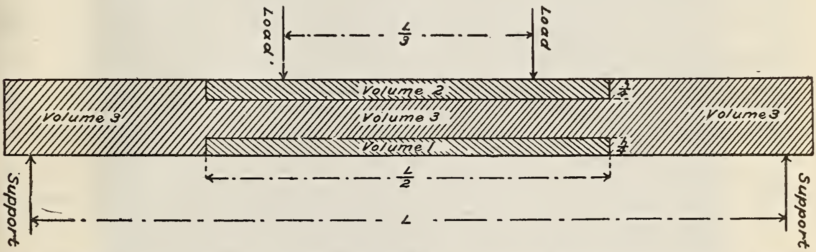


FIG. 4.—Method of dividing beams into three volumes so that they can be grouped according to location of knots.

ume 2 clear, form group 3. Both series of tests showed a considerable reduction in strength for material graded in group 1 as compared to the other two groups. The sticks in group 2 showed somewhat less strength than those in group 3. It was found that in volumes 1 or 2 large knots have more influence than small knots. Tests on western larch show that the same laws which hold for the other species referred to apply to this wood.

The effect of knots in compression parallel to the grain, for both green and air-seasoned material, is shown in Tables 5 and 6. In each table the specimens have been divided into four groups, as indicated at the left. At the bottom of the tables is given a comparison of results which shows that the crushing strength of clear material and material with pin knots is not materially different, while larger knots tend to reduce the strength in proportion to their size. Sound knots do not weaken wood subjected to test in compression perpendicular to grain. Such defects, therefore, are not objectionable in joists and plates which rest on sills or other supports.

[1] Plane between upper and lower halves when beam is horizontal.

TABLE 5.—*Effect of knots on strength in compression parallel to grain in green western larch.*

(6 by 6 by 24 inch specimens.)

Kind of knots.	Number of tests.	Rings per inch.	Moisture.	Weight per cubic foot.		Compressive strength at elastic limit.	Crushing strength at maximum load.	Modulus of elasticity.
				As tested.	Oven dry.			
			Per cent.	*Pounds.*	*Pounds.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*
None:								
Maximum	1	41.0	70.5	62.6	36.8	3,930	4,270	2,090
Average	51	25.4	52.3	44.8	29.3	[1] 2,635	3,630	[1] 1,528
Minimum	1	14.5	37.1	33.6	23.3	1,320	2,910	965
Pin knots (sound knots ½ inch or less in diameter):								
Maximum	1	29.0	64.5	52.6	32.6	3,630	4,060	2,561
Average	20	21.7	48.1	42.9	28.9	2,955	3,772	1,820
Minimum	1	10.0	34.0	38.1	26.3	1,650	3,370	1,323
Standard knots (sound knots between ½ inch and 1½ inches in diameter):								
Maximum	1	33.0	68.0	56.0	33.4	3,590	3,840	2,096
Average	28	24.2	44.5	39.2	27.0	2,577	3,226	1,521
Minimum	1	10.5	30.2	30.9	23.8	1,320	2,750	1,011
Large knots (sound knots larger than 1½ inches in diameter):								
Maximum	1	32.0	72.0	53.7	31.2	3,270	3,670	2,189
Average	8	23.8	[2] 46.2	40.5	[2] 27.8	2,569	3,069	1,442
Minimum	1	16.0	33.3	34.2	24.6	1,778	2,380	1,092
Ratios:								
Clear wood					1.00	1.00	1.00	1.00
Pin knots					.99	1.12	1.04	1.19
Standard knots					.92	.98	.89	1.00
Large knots					.95	.98	.85	.94

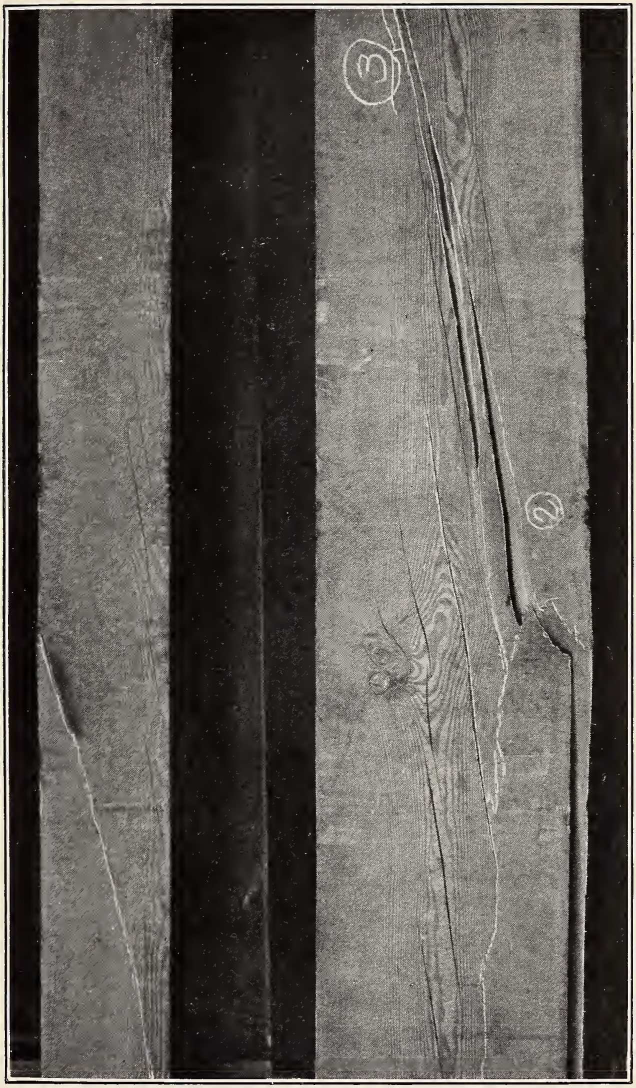
[1] Based on 50 tests. [2] Based on 6 tests.

TABLE 6.—*Effect of knots on strength in compression parallel to grain in air-seasoned western larch.*

(6 by 6 by 24 inch specimens.)

Kind of knots.	Number of tests.	Rings per inch.	Moisture.	Weight per cubic foot.		Compressive strength at elastic limit.	Crushing strength at maximum load.	Modulus of elasticity.
				As tested.	Oven dry.			
			Per cent.	*Pounds.*	*Pounds.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*
None:								
Maximum	1	43.5	18.3	49.9	42.9	5,380	9,280	2,727
Average	67	26.5	15.0	36.1	31.3	[1] 3,801	6,253	[1] 1,769
Minimum	1	15.0	12.4	28.3	25.0	2,560	4,920	1,260
Pin knots (sound knots ½ inch or less in diameter):								
Maximum	1	38.0	18.1	49.7	42.2	3,170	9,580	2,042
Average	[illegible]	24.3	[2] 15.8	35.5	[2] 30.7	[3] 3,165	5,994	[3] 2,025
Minimum	1	9.0	12.8	26.8	23.1	3,160	4,430	2,008
Standard knots (sound knots between ½ inch and 1½ inches in diameter):								
Maximum	1	33.0	18.2	43.2	36.6	2,830	6,350	1,655
Average	49	22.3	15.6	33.1	28.6	[4] 2,553	4,921	[4] 1,500
Minimum	1	9.0	13.2	23.8	21.0	2,320	3,650	1,305
Large knots (sound knots larger than 1½ inches in diameter):								
Maximum	1	30.0	16.5	36.3	31.5		5,480	
Average	8	22.9	15.5	31.8	27.5		4,520	
Minimum	1	12.0	14.8	30.0	26.1		3,910	
Ratios:								
Clear wood					1.00	1.00	1.00	1.00
Pin knots					.98	.83	.96	1.15
Standard knots					.91	.67	.79	.85
Large knots					.88		.72	

[1] Based on 12 tests. [2] Based on 68 tests. [3] Based on 2 tests. [4] Based on 3 tests.



Failure Due to Spiral Grain. Views of Side and Bottom of Central Portions of 8″ x 16″ x 16′ Stringer After Test.

SHAKES AND CHECKS.

Shakes are commonly ascribed to the action of the wind in moving the top of a tree back and forth, thus causing a strain at the base which sometimes results in a separation between annual rings. In some cases it is believed that shakes may be caused by freezing. They were the most serious defects found in the trees selected for test material.

Checks are radial cracks usually caused by more rapid seasoning on the surface than in the interior. They often occur in or near the neutral plane of a beam. Since a loaded beam tends to split in half along this plane, it is evident that shakes may weaken the resistance to longitudinal shear. In beams of small depth as compared to their span, the tendency to fail under test by shearing lengthwise is slight. In 8 by 16 inch beams tested over a 15-foot span the ratio of depth to span makes failure by shearing very likely, if the neutral plane is weakened. Table 7 shows the number of beams of various sizes that failed by longitudinal shear. The greater number of failures in the air-seasoned beams as compared to the green is due to checks formed in seasoning. The smaller proportion of shear failures in the 8 by 12 inch beams is due to their smaller depth.

TABLE 7.—*Western larch—Number of bridge stringers failing in shear—Span 15 feet.*

Number of pieces tested.	Condition of seasoning.	Cross section.	Number failing in shear.
32	Green	8 x 16	11
24	Air seasoned	8 x 16	14
30	Green	8 x 12	1
30	Air seasoned	8 x 12	6

CROSS GRAIN AND SPIRAL GRAIN.

Cross grain in timber may be caused by the deflection of the natural grain by knots, or by the timber being sawed at an angle to the heart of the log. Cross grain in the vicinity of knots is local, and may or may not be serious, depending upon its extent and position. Cross grain due to improper sawing is, as a rule, easy to detect. Spiral grain is due to the minute wood fibers being arranged spirally in the trunk of the tree, instead of vertically. The appearance of the visible grain (lines formed in cutting the annual rings) is not changed by spiral grain. It can, however, be detected by noting the position of the small checks which open up in seasoning. In sticks with spiral grain these checks appear at an angle to the visible grain. Similarly, the position of the pith rays (see Pl. III) is an indication of spiral grain, although they are usually difficult to detect. Plate IV shows bottom and side views of the central portion of a stringer in which the failure was due to spiral grain.

SAPWOOD.

Sapwood is objectionable because it decays more readily than heartwood. Western larch, however, contains such a small amount of sapwood that it need not be considered in the grading of structural timber.

RATE OF GROWTH.

The effect of rate of growth was studied for two classes of material—stringers with ordinary defects and small sticks without defects.

Stringers.—The average number of rings per inch in the test material was 24.3. Figure 5 shows the relation between the strength factors and rings per inch in green stringers. Stringers with serious defects were eliminated in this analysis. The average rate of growth is taken in four different ways—for the full cross section, for the upper and lower quarters together, for the upper quarter, and for the lower quarter. The four sets of curves are very similar and all show an appreciable decrease in the values for modulus of rupture, fiber stress at elastic limit, and modulus of elasticity as the number of rings per inch increases.

The analysis shown in figure 2, however, includes results of tests on all grades of stringers. The timbers are arranged in order of their strength based on the modulus of rupture, and the average rate of growth in each stringer is plotted. This figure shows that when all grades are considered the rate of growth has but little significance in indicating the strength properties of this class of material. The lines showing average rate of growth for both green and seasoned stringers show little tendency to vary from the horizontal in passing from the stronger to the weaker timbers.

Small sticks.—The relation between mechanical properties and rate of growth as determined from tests on small, clear specimens is shown in figure 6. The maximum strength values occurred in sticks with from 17 to 24 rings per inch; the heaviest sticks also had from 17 to 24 rings to the inch.

WEIGHT.

There is a close relation between the dry weight of wood and its strength properties, though this relation is more marked in some classes of material than in others.

Stringers.—The general relation between weight and strength in stringers is shown in figure 2, in which a decrease in weight accompanies a decrease in the several strength values. While this holds as a general law, the results of individual tests show much variation, and some of the very heaviest pieces fell among timber of lowest strength. This may be accounted for by the fact that the influence of weight is often more than offset by the effect of defects.

Small sticks.—The relation between weight and strength properties is more clearly marked in small, clear pieces than in stringers, as

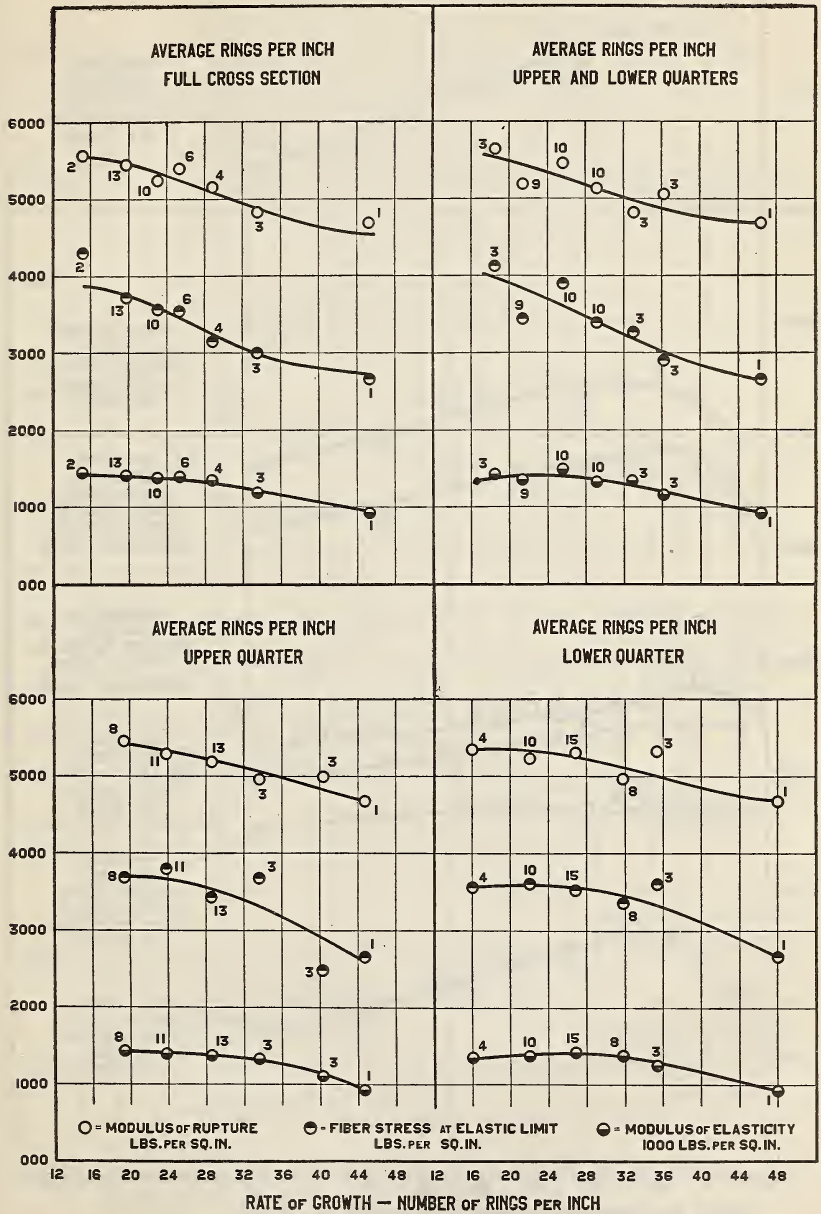


FIG. 5.—Relation of strength values to rate of growth in western larch bridge stringers; determined for rate of growth in various parts of cross section.

shown in figure 7, in which the strength values of small, clear pieces are plotted against their dry weight. In material varying from 23 to

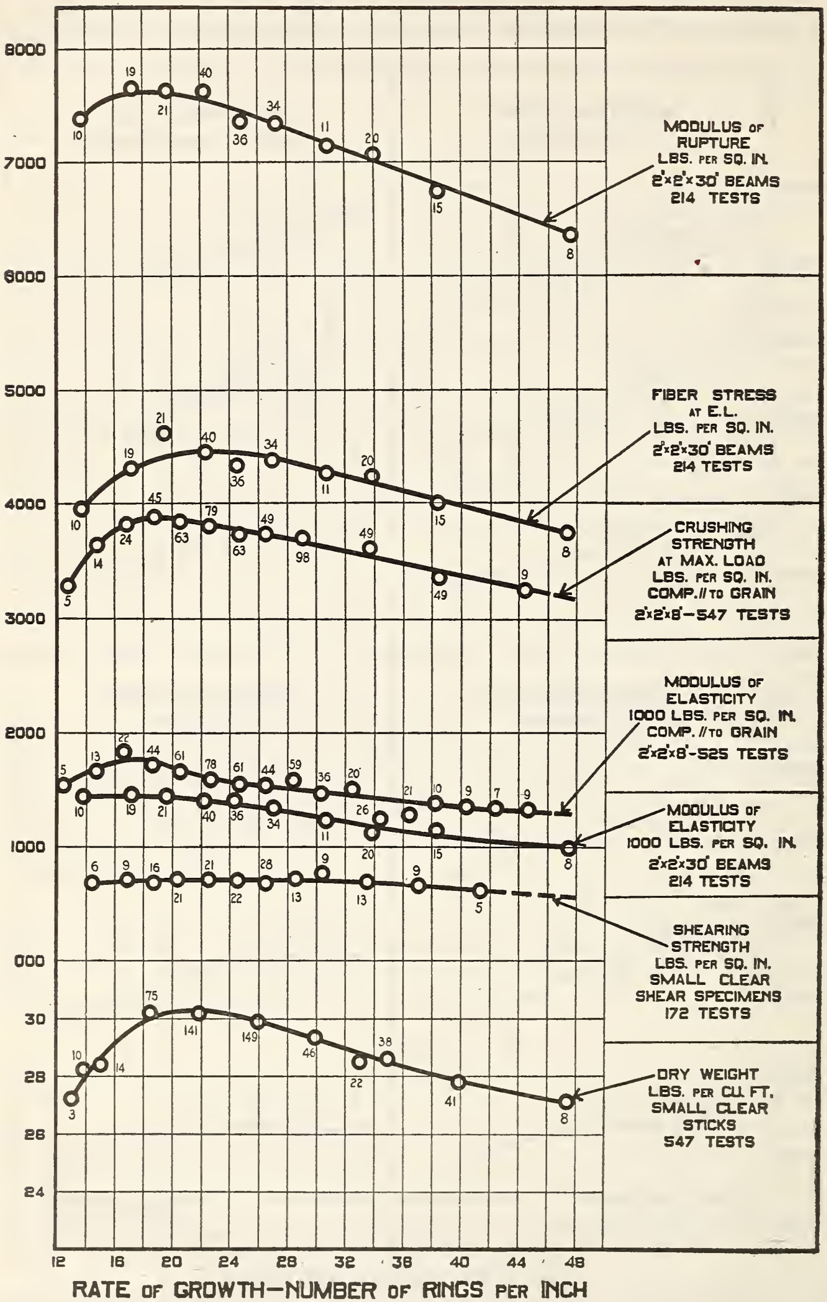


FIG. 6.—Relation of strength values and weight to rate of growth, small, clear pieces, green western larch.

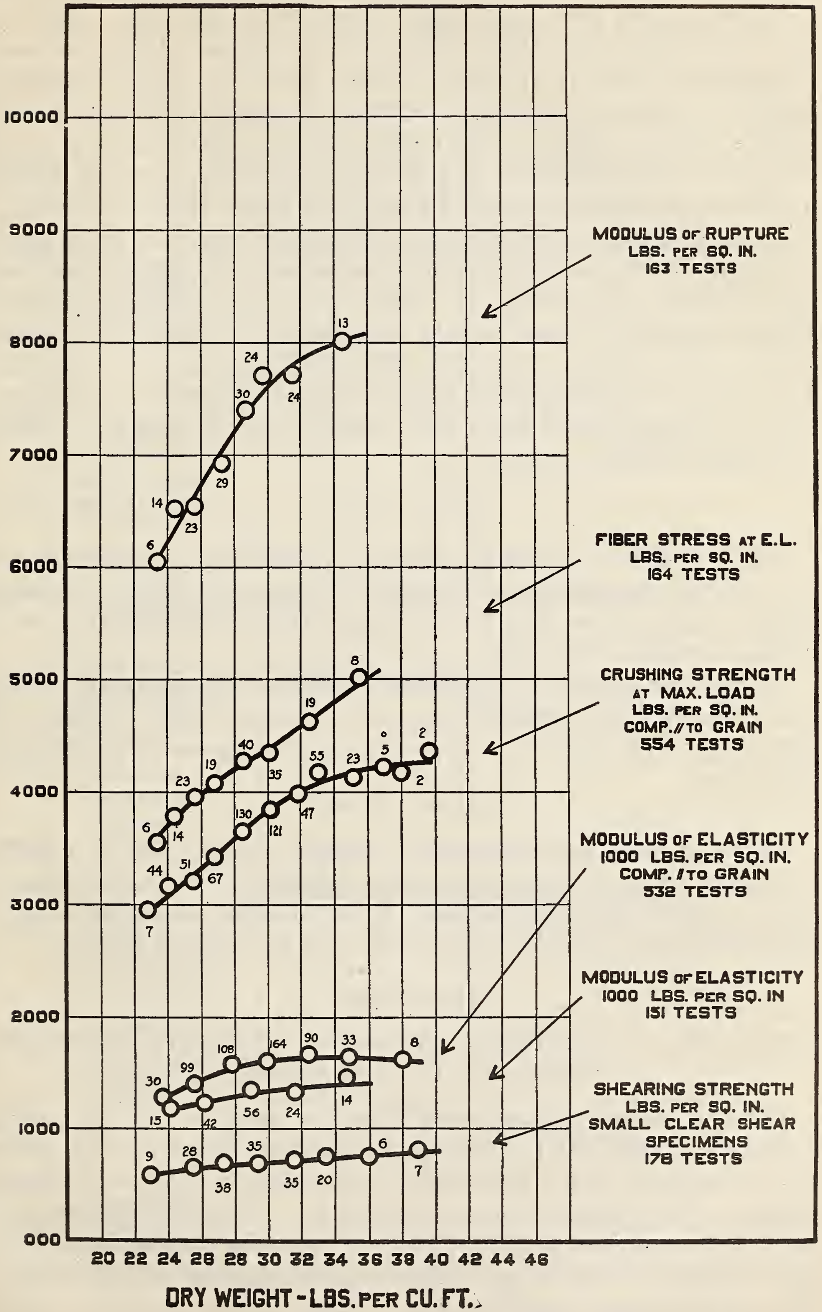


FIG. 7.—Relation of strength values to dry weight, small, clear sticks, green western larch.

34 pounds per cubic foot the modulus of rupture increased from 6,100 to 8,000 pounds per square inch, a gain of 31 per cent. Since in small, clear specimens there seems to be a definite relation between strength and rate of growth, and also between strength and dry weight, it follows that there must be a relation between rate of growth and dry weight. This relation is shown in the bottom curve of figure 6, from which it appears that the rate of growth in the heaviest sticks varied from 17 to 24 rings per inch. Since the summerwood in the annual rings is heavier and stronger than the springwood, it is apparent that sticks with the same number of rings per inch but with different proportions of summerwood will vary in strength. Hence weight is a more certain criterion of strength than rate of growth. It seems to be a fact, however, in a number of species tested by the Forest Service, that the largest proportion of summerwood is generally associated with certain rates of growth, the rate differing in different species.

AGE OF TREE.

Figure 8 shows the relation between the strength properties of old trees and of younger trees. Stringers cut from the central portions of the younger trees were heavier and stronger than those cut from similar portions of old trees.

All the sticks tested in compression parallel to grain had the same rate of growth, even though from trees of different ages. In this way any effect which might be caused by a variation in rate of growth was eliminated.

HEIGHT IN TREE.

Figure 9 shows the comparative strength of pieces cut at various heights in trees of approximately the same age. The heights represented ranged from 12 to 60 feet. The figure shows that the strongest and heaviest material comes from the lower part of the tree.

SEASONING.

DISTRIBUTION OF MOISTURE AND RATE OF SEASONING IN BRIDGE STRINGERS AND CAR SILLS.

Moisture determinations were made on sections cut from each stringer and sill tested to ascertain the moisture content of the pieces as a whole, and the distribution of moisture throughout the cross section. The results are shown in figure 10. The green stringers had an average moisture content of 50.9 per cent with a variation of from 44.8 per cent in the outer portions to 54.4 per cent in the interior. This difference was doubtless due to slight surface seasoning which occurred between the time of sawing and testing. The green car sills contained 53.3 per cent moisture in the surface portions and 57.9 per

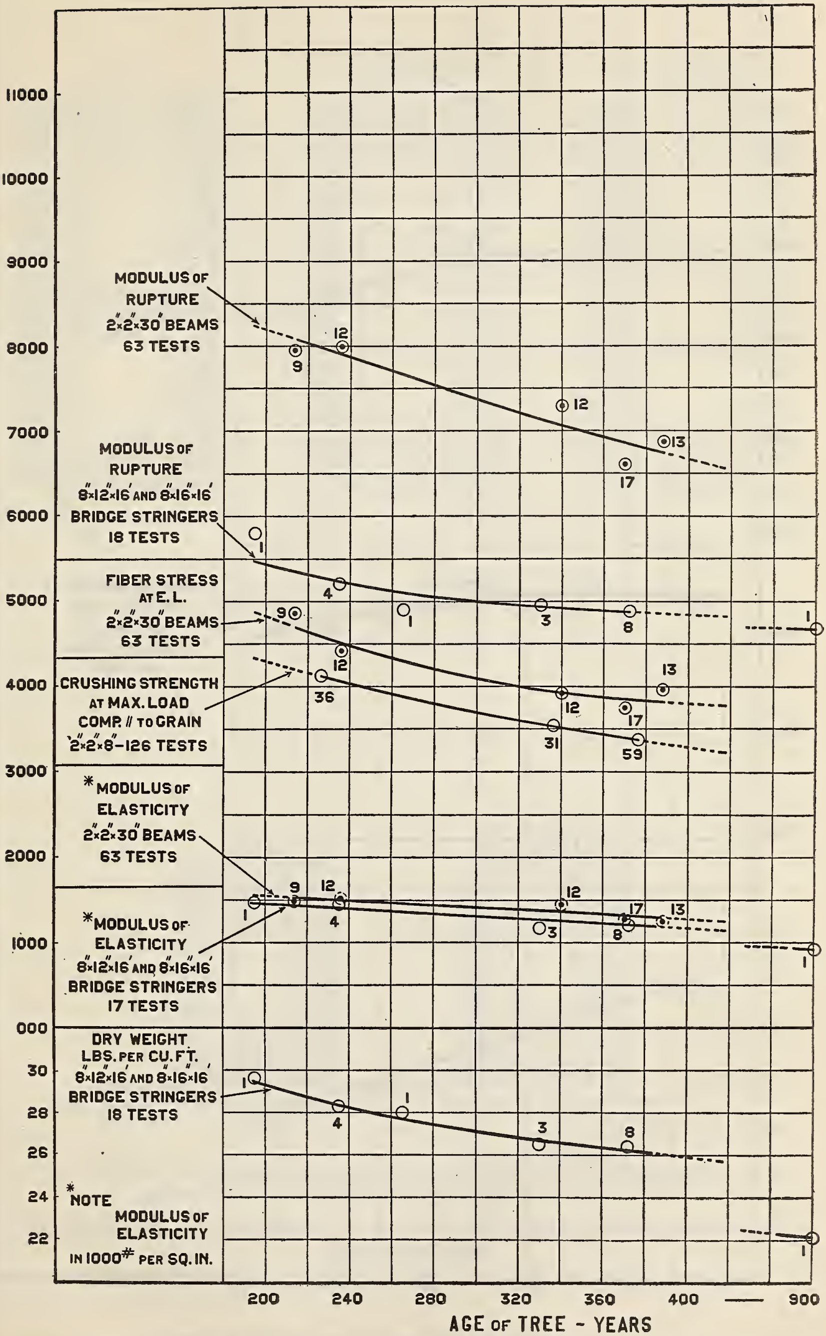


FIG. 8.—Relation between strength values in material cut from western larch trees of various ages.

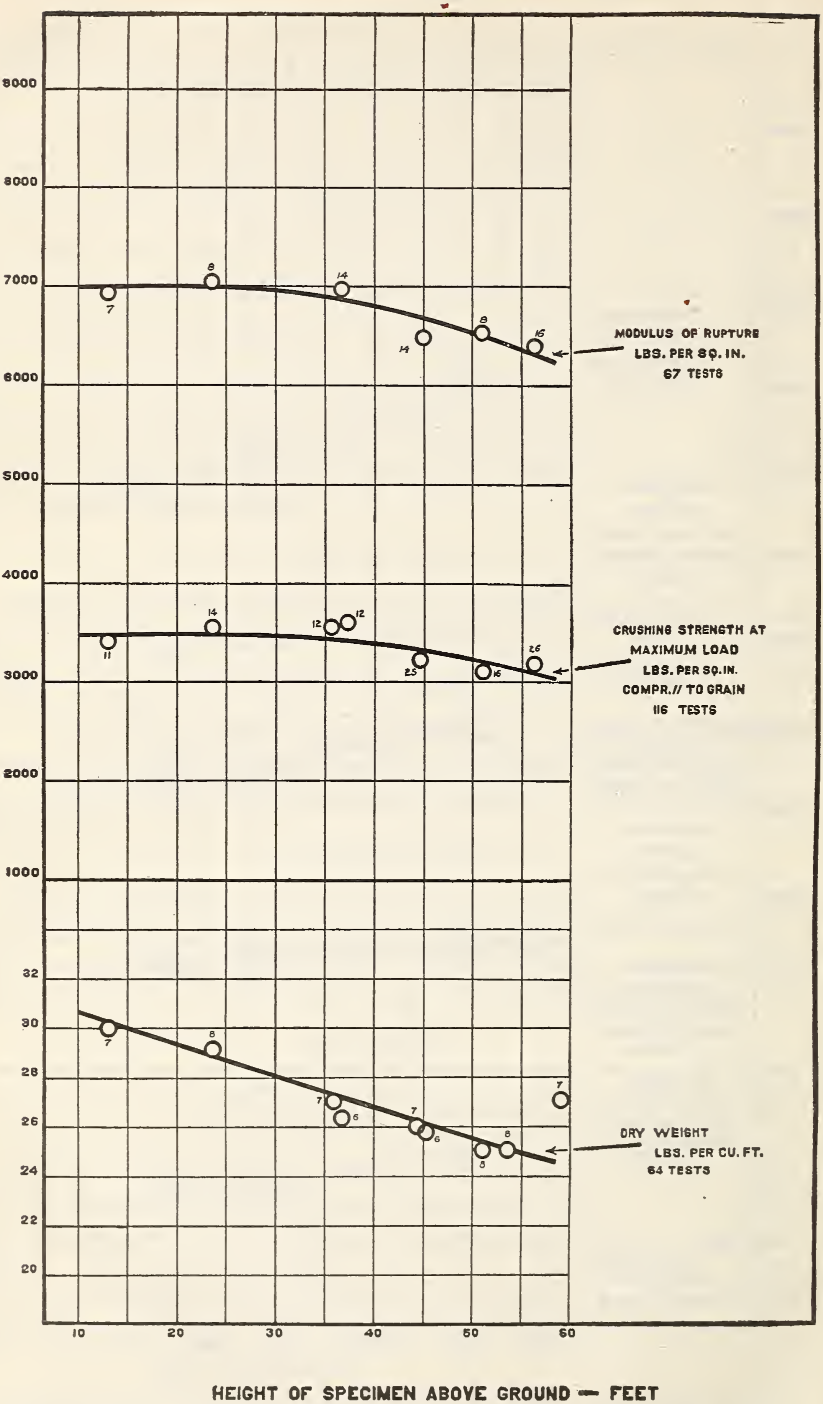
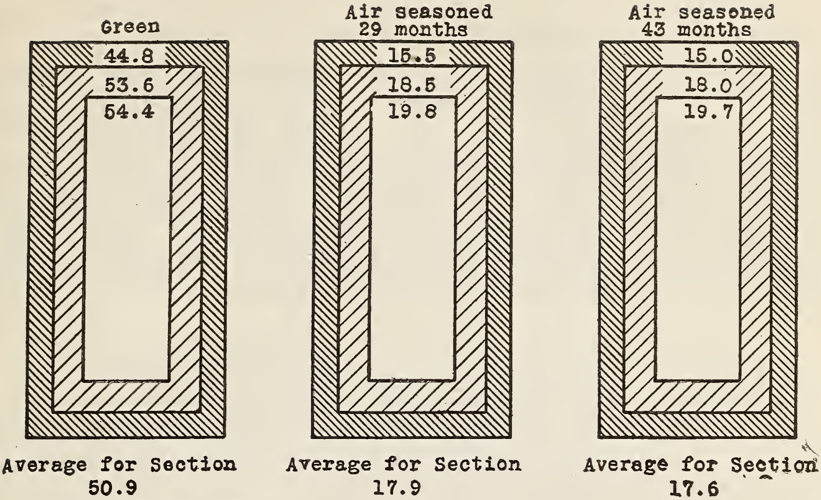
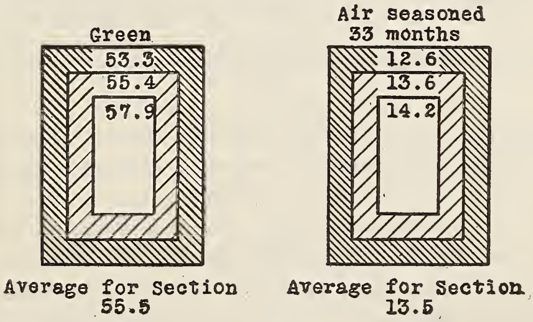


FIG. 9.—Relation of strength values to height in tree, small, clear pieces, green western larch.



Average moisture distribution in sections cut from green and air-seasoned bridge stringers.



Average moisture distribution in sections cut from green and air-seasoned car sills.

Fig. 10.—Summary of moisture determinations made upon green and seasoned bridge stringers and car sills of western larch.

cent in the interior. The stringers and sills were air seasoned in an open pile under cover for varying periods. There were two groups of stringers, one air seasoned for 29 months and the other for 43 months. Both showed the same average moisture content when tested, and practically the same moisture distribution, indicating that a period of air seasoning not exceeding 29 months is sufficient to bring western larch stringers to a constant moisture condition under weather conditions obtaining about Seattle. The car sills after seasoning for 33 months showed an average moisture content of 13.5 per cent, as compared to 17.8 per cent in the stringers. The moisture content in various parts of the cross sections was also lower than for the stringers. The fact that the car sills seasoned for 33 months lost more moisture than the group of stringers seasoned for 43 months shows the greater

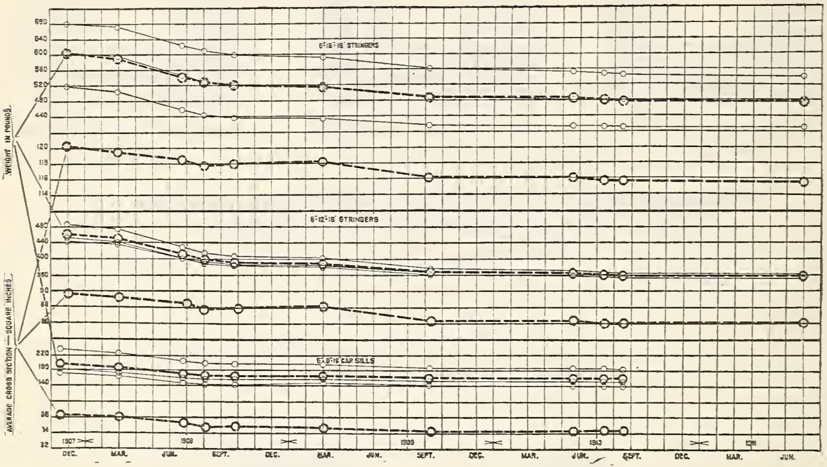


FIG. 11.—Rate of seasoning and the resulting amount of shrinkage in bridge stringers and car sills of western larch.

degree of seasoning that occurs in smaller sizes. The loss in weight which may be brought about by seasoning stringers and car sills for different periods of time is shown in figure 11.

All of this material was open-piled under cover, and weighings and measurements were taken from time to time on three pieces of each size. Figure 11 shows that the 8 by 16 inch by 16 foot timbers lost an average of 84 pounds, or 13.9 per cent, of the original weight during the first 10 months. After a period of 43 months a loss of 128 pounds per stringer, or 21.2 per cent, was shown.

The 8 by 12 inch by 16-foot stringers seasoned a little more rapidly the first 10 months, effecting an average loss of 75 pounds, or 16.3 per cent. After seasoning for 43 months the average loss per stringer was 110 pounds, or 23.9 per cent.

During the first 10 months the car sills lost an average of 31 pounds, or 16.3 per cent, while at the end of 33 months a loss of 37 pounds per sill, or 18.9 per cent, was shown.

SHRINKAGE.

The shrinkage or swelling of wood is caused by a decrease or increase of moisture.

Stringers.—Measurements of the cross sections of the stringers reserved for air seasoning were made at the time of each weighing. Shrinkage lengthwise is so small as to be negligible except in very long timbers. The contraction in cross section during drying is shown in figure 11. The shrinkage in the cross section in changing from a green to an air-dried state amounted to between 4 and 5 per cent.

Small sticks.—Shrinkage tests were made also on small, clear specimens 3 by 3 by 3 inches. The pieces were cut so that two sides showed flat grain and two sides edge grain. The specimens were gradually air seasoned, and then dried in an oven at 100° C. until all moisture was removed. Measurements to determine the change in the size of the pieces were taken at various conditions of moisture. The results of these measurements are plotted in figure 12. With practically all kinds of wood, the absorption of water beyond a certain point has no effect upon the volume. For western larch the figure shows this point to be a condition of 29 per cent moisture. Below 29 per cent the area of the cross section contracts in direct proportion to the moisture loss. After oven drying was completed the pieces were placed on a shelf in the laboratory and allowed to reach constant weight. The point designated "absorption point" in figure 12 shows that in doing this they absorbed about 8 per cent moisture from the air and increased 3.8 per cent in cross section.

The total radial, tangential, and longitudinal shrinkage of western larch was 4.4, 8.7, and 0.2 per cent, respectively, and the total volumetric shrinkage was 14.3 per cent. These percentages are based on the measurements of dry wood.

STRENGTH AS AFFECTED BY SEASONING.[1]

Reduction of the amount of moisture in wood is accompanied by an increase in strength. The ratio of the strength of air-seasoned to green material is shown at the bottom of Table 2. Increase in strength with drying is greater in small than in large pieces, since, in the case of the former, serious defects are not likely to result from seasoning, while in large timbers, though the strength of the wood

[1] For a more detailed discussion of the effect of moisture see Forest Service Bulletin 70, Effect of Moisture Upon the Strength and Stiffness of Wood.

itself may be increased, yet the beam as a whole may be weakened on account of defects formed in the process of drying.

The effect of varying degrees of moisture on the strength and stiffness of small, clear beams and columns is shown in figure 13. Above a certain moisture per cent (in western larch between 27 and 30) a further increase in moisture had no effect on the strength values, while below that per cent a further removal of moisture caused a marked increase in strength.

The curves in figure 13, which show the effect of seasoning upon the modulus of rupture and modulus of elasticity, indicate smaller values for thoroughly dry wood than for wood containing about 3 per cent moisture. To remove the final 3 per cent of moisture by drying

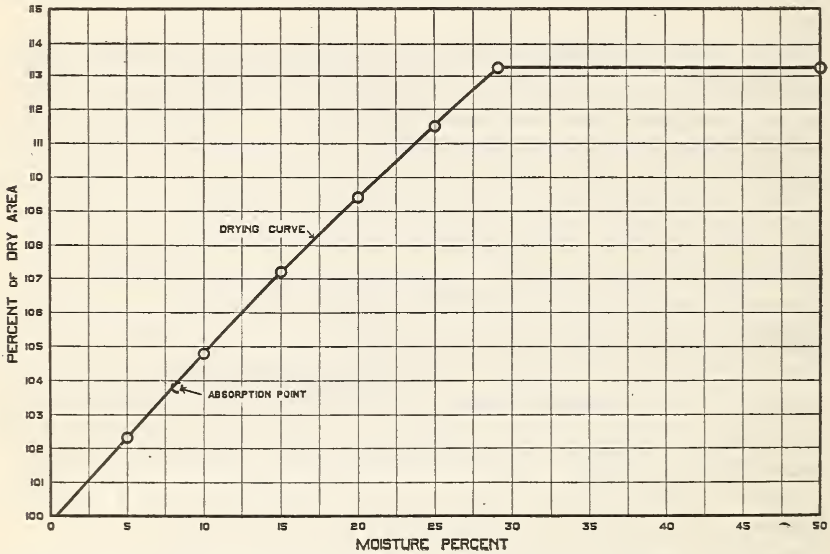


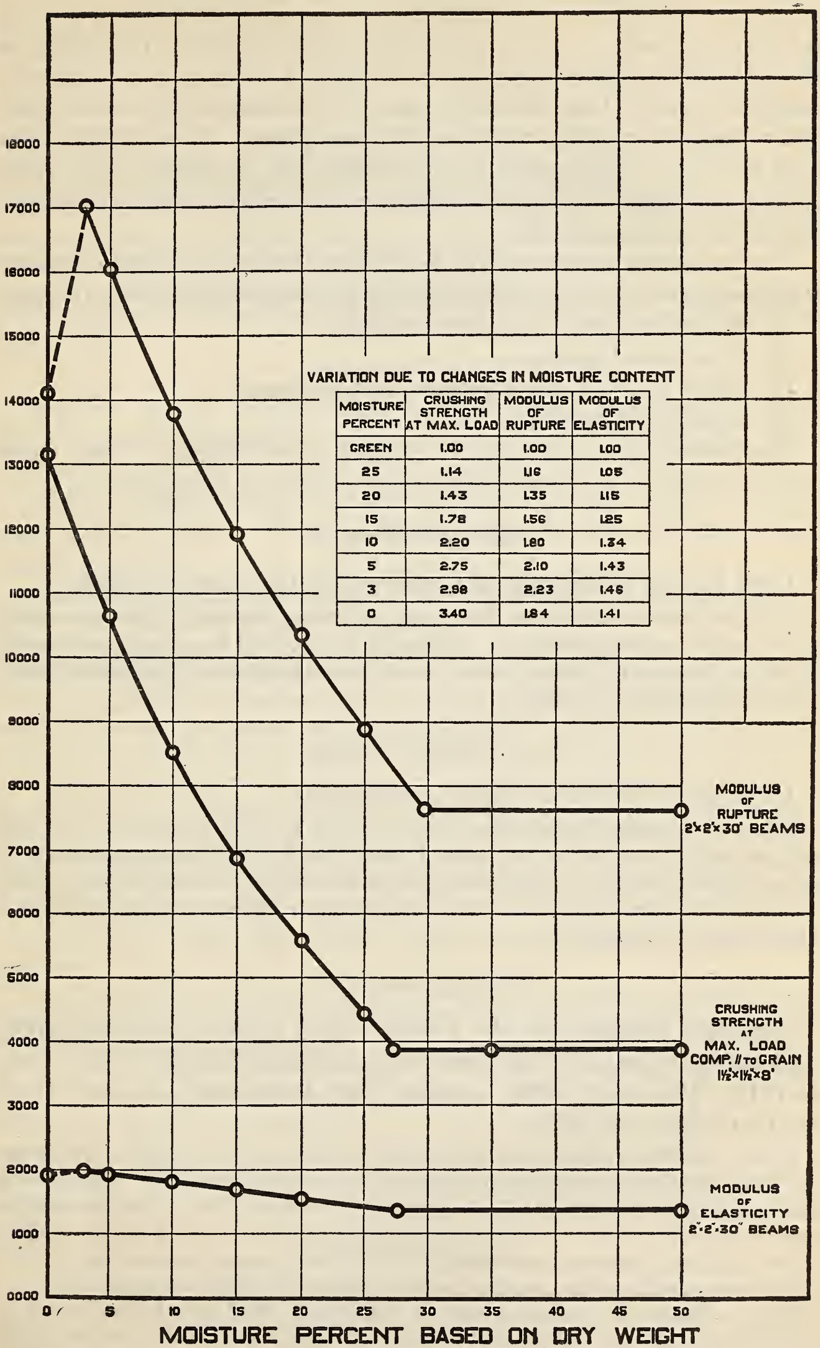
FIG. 12.—Relation between the moisture content and the cross section of small, clear specimens of western larch.

the wood at 100° C. renders it intensely brittle. This brittleness greatly affects the strength in bending, but does not influence the strength in compression parallel to grain.

The tests to determine the effect of rate of growth, dry weight, etc., on the mechanical properties were all made on green material, in order to eliminate the effect of moisture.

GRADING RULES AND SPECIFICATIONS.

The purpose of grading rules is to divide structural material into groups according to its strength and stiffness, based on the appearance of the individual sticks. It is ever becoming more and more difficult to secure high-grade structural material, both on account



VARIATION DUE TO CHANGES IN MOISTURE CONTENT

MOISTURE PERCENT	CRUSHING STRENGTH AT MAX. LOAD	MODULUS OF RUPTURE	MODULUS OF ELASTICITY
GREEN	1.00	1.00	1.00
25	1.14	1.16	1.05
20	1.43	1.35	1.16
15	1.78	1.56	1.25
10	2.20	1.80	1.34
5	2.75	2.10	1.43
3	2.98	2.23	1.46
0	3.40	1.84	1.41

FIG. 13.—Effect of varying degrees of moisture upon the strength and stiffness of small, clear specimens of western larch.

of the poorer quality of logs cut in the woods and of the increasing tendency of mills to saw clear material into boards. The result is that structural timber found on the market to-day has a much wider range in quality than formerly, and the necessity for efficient and easily applied grading rules has become plain. The grading rules now in use in various parts of the country are, as a rule, either very general and loose or else are so drawn as to exclude everything except the highest-grade material.

The points for consideration in grading timber, aside from general requirements as to size, soundness, sawing, and freedom from rot, are:

(1) Knots (position, size, and number).

(2) Checks and shakes.

(3) Grain (rapid or slow growth, straightness).

(4) Amount of sapwood.

The following are examples of grading specifications. Some cover only one class of material while others include several grades:

SPECIFICATION A.

Used by one of the leading transcontinental railway systems:

All timber must be of the best description of the kind required. It must be sawed square and to proper dimensions. It must be free from all loose, large, or unsound knots, sap, sun cracks, shakes, wanes, or other imperfections or defects which would impair its strength or durability.

SPECIFICATION B.

Used by the Isthmian Canal Commission:

Stringers.—Douglas fir shall show not less than 85 per cent heart on any face and not less than 70 per cent on any edge; it shall show not less than an average of 12 annual rings to the inch. Sound knots less than 3 inches in diameter shall be permitted in the vertical faces of the stringer at points not less than one-fourth the depth from the edge of the piece.

SPECIFICATION C.

Standard adopted by the Pacific Coast Lumber Manufacturers' Association (now the West Coast Lumber Manufacturers' Association) in 1911. But very slight changes have been made in this set of grading rules since 1899:

Clears.—Shall be sound lumber well sawed, one side and two edges free from knots and other defects impairing its use for the probable purpose intended. Will allow in dimensions larger than 6 by 10 inches pitch pockets when not extending through the piece; light-colored sap on corners not exceeding 3 inches on face and edge, knots 2 inches and less in diameter, according to size of piece, when on one face and one-half of each corresponding edge, leaving one face and upper half of each edge clear.

Selects.—Shall be sound, strong lumber, well sawed. Will allow in sizes over 6 by 6 inch knots, not to exceed 2 inches in diameter, varying according to the size of the piece; sap on corner not to exceed 2 inches on both face and edge; pitch pockets not

to exceed 6 inches in length. Defects in all cases to be considered in connection with the size of the piece and its general quality.

Merchantable.—This grade shall consist of sound, strong lumber, free from shakes, large, loose, or rotten knots, and defects that materially impair its strength, well manufactured, and suitable for good, substantial constructional purposes. Will allow slight variations in sawing, sound knots, pitch pockets, and sap on corners, one-third the width and one-half the thickness, or its equivalent. Defects in all cases to be considered in connection with the size of the piece and its general quality. In timber 10 by 10 inches and over sap shall not be considered a defect. Discolorations through exposure to elements, other than black sap, shall not be deemed a defect excluding lumber from this grade if otherwise conforming to merchantable grade.

Common.—This grade shall consist of lumber having knots, sap, and other defects which exclude it from grading as merchantable, but of a quality suitable for rough kinds of work.

SPECIFICATION D.

Prepared by the American Society for Testing Materials and with slight changes adopted by the American Railway Engineering Association.

Standard specifications for Douglas fir and western hemlock bridge and trestle timbers. To be applied to single sticks and not to composite members:

Standard heart grade.—Shall include yellow and red Douglas fir and western hemlock. White Douglas fir will not be accepted.

General requirements.—All timber shall be live, sound, straight, and close-grained, cut square-cornered, full length, not more than one-fourth inch scant in any dimension for rough timber or one-half inch for dressed timber; free from large, loose, or unsound knots, knots in groups, or other defects that will materially impair its strength for the purpose for which it is intended. Subject to inspection before loading.

Stringers.—Shall show not less than 90 per cent heart on each side and edge measured across the surface anywhere in the length of the piece. Shall be out of wind and free from shakes, splits, or pitch pockets over three-eighths of an inch wide or 5 inches long. Knots greater than 2 inches in diameter will not be permitted within one-fourth of the depth of the stringer from any corner nor upon the edge of any piece; knots shall in no case exceed 3 inches in diameter.

Standard grade.—Shall include yellow, red, and white Douglas fir and western hemlock.

General requirements.—All timbers shall be sound and cut square-cornered, except that timbers 10 by 10 inches in size may have a 2-inch wane on one corner, or its equivalent on two or more corners. Other sizes may have proportionate defects. Must be free from defects which will impair its utility for temporary work. Knots shall not exceed one-fourth the width of the surface of the piece in which they occur. Subject to inspection before loading.

Stringers.—Shall be out of wind, free from shakes or splits extending over more than one-eighth of the length of the piece, or knots more than 4 inches in diameter. Knots greater than 3 inches in diameter will not be permitted on the edge of any stringer.

SPECIFICATION E.

Rules proposed by the Forest Service to be applicable to structural timber of all species, and to be supplemented by suitable general requirements.

In connection with this specification it is necessary to give the following definitions[1] regarding defects and the general quality of the wood:

Dense wood.—Wood which is resilient; that is, when struck with a hammer or similar blunt instrument it must give a sharp, clear sound, and the hammer must show a marked tendency to rebound and the wood to recover from the effect of the blow.

Class 1 knots.—Class 1 knots must be solid, firmly attached to the surrounding wood, and cause no marked irregularity in the grain of the timber. Small spike knots will be included in this class.

Class 2 knots.—Class 2 knots must be solid, but are insecurely attached to the surrounding wood, or associated with burl or other irregularity in the grain.

Class 3 knots.—Class 3 knots are unsound knots; that is, they are softer than the surrounding wood.

Diameter of knots.—The diameter of a knot on the narrow face of a timber will be its projection on a line perpendicular to the edges of this face. On the wide or vertical face the smallest dimension of a knot is taken as its diameter.

Small knots.—Knots less than $1\frac{1}{2}$ inches in diameter.

Large knots.—Knots $1\frac{1}{2}$ inches or more in diameter.

The following general requirements are considered applicable to western larch timbers:

General requirements—Bridge stringers.—All timbers shall be cut from live, sound trees 28 inches or less in diameter breast high. Timbers shall be cut square-cornered, full length, and not more than one-fourth inch scant when rough, and one-half inch scant when dressed. Special care shall be used to guard against wind shakes. Such shakes should not be confused with pith checks that appear when the logs are sawed so as to expose the center of the tree.

Grade 1 timbers.

(*a*) Must contain only dense wood.
(*b*) Must not have class 2 or class 1 knots in volume 1.[2]
(*c*) Must not have large class 2 knots in volume 2.
(*d*) The aggregate diameter of knots on any face within the center half of the length shall not exceed the width of the face.
(*e*) Must not have shakes or deep checks.
(*f*) Must not have diagonal or spiral grain with a slope greater than 1 inch in 20.

Grade 2 timbers.

(*a*) Must contain only dense wood.
(*b*) Must not have large class 2 knots in volume 1.
(*c*) The aggregate diameter of knots on any face in the center half of the length shall not exceed two times the width of the face.
(*d*) Must not have shakes extending along an annual ring a distance greater than the width of the piece.

DISCUSSION OF GRADING RULES.

An examination of the five specifications shows their wide variation.

[1] More fully discussed in Forest Service Bulletin 108, Tests of Structural Timbers, by McGarvey Cline and A. L. Heim.

[2] See figure 4.

SPECIFICATION A.

The wording of specification A is very general, and practically the whole matter of the acceptance or rejection of the material is left to the judgment of the inspector, a procedure which may or may not result satisfactorily. Inspection under this specification should, of course, be made before the timber is loaded for shipment in order to protect the seller; otherwise, a large part of the shipment might be rejected when inspected at the place of delivery.

SPECIFICATION B.

Specification B is rigid as far as knots are concerned. Very few of the stringers included in the larch test material could pass such an inspection.

SPECIFICATION C.

Specification C has given fair satisfaction on the Pacific coast. It provides for separating timber into four different grades. It contains no limitations in regard to the position of knots and leaves much to the judgment of the inspector. Grading is generally done while the material is still green, or at least only partially air seasoned.

Table 8 shows the average values for green stringers graded according to this specification. At the bottom of the table the ratios of the average values are shown. These ratios show a decrease in the average strength values from clear to common grade, and indicate that so far as average strength is concerned this method of grading serves its purpose. In testing the efficiency of grading rules, however, range in strength is more important than average values. From the maximum and minimum values included in the table it will be seen that the strongest stick was in the lowest grade. In diagram 2 the kind of circle, as indicated in the legend, shows the grade of the piece. The sprinkling of the various grades throughout the curves for modulus of rupture of both green and air-seasoned timber shows that there is considerable uncertainty in judging the mechanical properties of timber by specification C.

TABLE 8.—*Results of tests of green western larch bridge stringers graded in accordance with the specifications of the West Coast Lumber Manufacturers' Association.*

(8 by 16 inches by 16 feet and 8 by 12 inches by 16 feet—15-foot span.)

Grade.	Number of tests.	Rings per inch.	Moisture.	Weight per cubic foot.		Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.
				As tested.	Oven-dry.			
			Per cent.	*Pounds.*	*Pounds.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*
Clear and select:								
Maximum	1	45.4	66.8	53.0	33.4	4,770	7,310	1,748
Average	23	24.9	51.7	42.2	27.8	3,543	5,486	1,344
Minimum	1	18.0	38.8	34.6	22.1	2,050	3,640	694
Merchantable:								
Maximum	1	30.8	63.3	51.0	33.5	4,300	6,360	1,708
Average	21	22.6	48.6	42.5	28.6	3,427	4,805	1,336
Minimum	1	13.9	38.0	36.5	25.5	1,989	2,770	1,025
Common:								
Maximum	1	38.0	64.5	53.3	34.0	5,290	7,340	1,823
Average	18	25.4	51.7	43.6	28.7	2,926	4,317	1,204
Minimum	1	20.4	40.0	33.3	23.2	1,810	2,500	842
Clear and select ratio					1.00	1.00	1.00	1.00
Merchantable ratio					1.03	.97	.88	.99
Common ratio					1.03	.83	.79	.90

SPECIFICATION D.

Specification D provides for two grades of material, "standard heart" and "standard." The "General requirements" leave to the inspector the decision as to what defects influence strength. Table 9 shows the average values for green western larch stringers graded according to this specification. The group designated "culls" was formed in order to include all sticks found below "standard." The ratios given at the bottom of Table 9 show larger differences between the average strength of the three groups than do the ratios in Table 8. The average values for strength are higher in the highest and lower in the lowest grade by specification D than by specification C. This fact indicates more efficient grouping by the application of specification D. An examination of the maximum and minimum values in Table 9 shows, however, that the strongest and stiffest stick fell in the intermediate grade, and that the strongest stick in the cull grade was considerably stronger than the weakest stick in the standard grade.

TABLE 9.—*Results of tests of green western larch bridge stringers graded in accordance with the specifications of the American Railway Engineering Association.*

(8 by 16 inches by 16 feet and 8 by 12 inches by 16 feet—15-foot span.)

Grade.	Number of tests.	Rings per inch.	Moisture	Weight per cubic foot.		Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.
				As tested.	Oven-dry.			
			Per cent.	*Pounds.*	*Pounds.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*
Standard heart:								
Maximum	1	36.7	63.3	53.0	33.4	4,670	7,310	1,748
Average	16	23.3	49.4	43.2	29.0	3,691	5,826	1,450
Minimum	1	13.9	38.8	34.6	24.5	2,680	4,270	1,097
Standard:								
Maximum	1	30.2	66.8	53.3	34.0	5,290	7,340	1,823
Average	24	22.7	52.2	43.9	28.8	3,451	5,121	1,346
Minimum	1	16.5	40.5	36.5	24.9	2,050	2,910	694
Culls:								
Maximum	1	38.0	64.3	51.9	31.6	4,770	5,940	1,717
Average	20	25.6	49.2	41.4	27.6	2,876	4,013	1,151
Minimum	1	14.4	38.0	33.3	23.2	1,810	2,500	842
Standard heart ratio					1.00	1.00	1.00	1.00
Standard ratio					.99	.94	.88	.93
Culls ratio					.95	.78	.69	.79

SPECIFICATION E.

In framing the proposed rules it was the aim to provide a means of dividing serviceable structural timbers into two groups, one group to contain all sticks above and the other all sticks below a certain

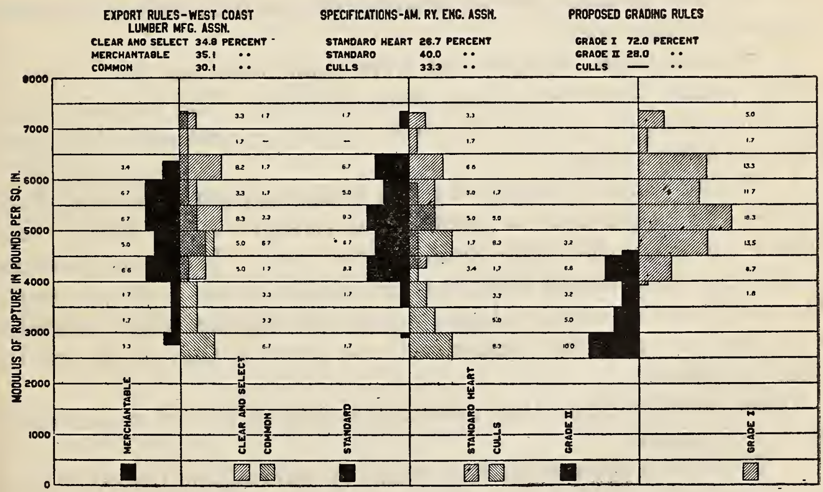


FIG. 14.—Diagram showing range in strength of the various grades in each of three sets of grading rules. Green western larch bridge stringers.

strength. Figure 14 shows a graphical comparison of specifications C, D, and E. The percentage of the total number of pieces tested which fall in the different grades are shown at the top for each specification.

It is evident from figure 14 that the proposed rule admits a larger number of timbers to the highest grade than either of the other specifications.

By applying specification E to the timbers tested they are grouped so that pieces in which the modulus of rupture ranges from 4,000 to 7,300 pounds per square inch are placed in grade 1, and those in which this factor varies from 2,500 to 4,600 pounds per square inch are placed in grade 2. Comparing the results shown for the three specifications in figure 14, the proposed rule shows a much less overlapping of strength values in the different grades.

CONCLUSIONS.

The principal conclusions drawn from the results of the tests on western larch may be summarized as follows:

1. Sound knots may or may not weaken beams, depending upon their size, position, and character. Knots usually have less weakening effect in columns than in beams. Sound knots do not weaken wood loaded in compression perpendicular to the grain.

2. Wind-shake, cross grain, and spiral grain are serious defects. Wind-shakes are very common in the butt section of larch trees, especially in mature timber. Cross grain near the edge of a timber will reduce its strength.

3. A much greater gain in strength results from seasoning small pieces than large ones.

4. Western-larch stringers cut from small trees are apt to be of better quality than those taken from old trees. The material coming from the upper portion of a tree exhibits less strength than that from the lower portion.

5. The maximum strength of green bridge stringers (average of all grades) is 67.9 per cent as great as the strength of the small, clear beams cut from the larger timbers after test. The corresponding ratio between seasoned stringers and small beams is 57 per cent. The maximum strength of large, green, and seasoned short columns is 95 and 96.9 per cent, respectively, as great as that of the small, clear specimens.

These ratios indicate that defects are more serious in beams than in short columns.

6. The rate of growth has little value in determining the structural properties of large timbers containing weakening defects.

7. The dry weight of wood free from defects is an excellent indication of its strength.

8. The results of tests made by the Forest Service upon structural timbers of Douglas fir, western hemlock, and western larch show the following relative strength ratios:

	Per cent.
Douglas fir	100.0
Western hemlock	88.0
Western larch	81.7

These figures are based on the average modulus of rupture of all grades of large timbers.

9. Some of the specifications now in use for the grading of structural timber are too severe, and others are very indefinite. The proposed rules gave a better grouping for the western-larch timbers than any other grading rules applied.

STRUCTURAL USES.

In some parts of northern Idaho, western Montana, and eastern Washington western larch and western yellow pine are practically the only woods used for building purposes. Outside of its region of growth western larch is rarely found on the market.

Table 10 shows the principal products into which western larch was cut in the States of Oregon, Washington, Montana, and Idaho in 1909.

TABLE 10.[1]—*Western larch reported cut into various forms in the States of Oregon, Washington, Idaho, and Montana in 1909.*

Form.	Amount.	Value.
Lumber and lath, feet B. M	264,022,000	$3,270,906
Crossties [2]	3,311,000	1,356,000
Staves,[2] slack cooperage	28,832	143,189
Heading,[2] slack cooperage	1,280	44,600
Veneer, feet B. M	100,000	1,200
Poles [2]	29,889	18,282
Total		4,834,177

[1] The above table is compiled from Bureau of the Census Bulletin, "Forest Products of the United States, 1909."
[2] Includes tamarack from Michigan, Minnesota, and Wisconsin.

Western larch yields an average of about 10 per cent of clear lumber. This low yield is due in part to the prevalence of shakes in the butt cuts and in part to the practice of butting off the swelled portions at the base of the trunk to prevent loss in rafting. The swelled butts are heavier than the rest of the trunk, and will usually sink.

A cut of 25,000,000 board feet of western larch at Seeley Lake, Mont., show a loss in the woods of 8 per cent from butting off the lower portion of the trees. The length of the "butts" ranged from

4 to 8 feet, and occasionally a 16-foot log had to be rejected. Above the first 16-foot log the loss due to wind shakes is negligible.

There was a loss of about 3 per cent due to white and brown rot.

DURABILITY.

Reliable data regarding the lasting qualities of western larch are not available. Among consumers the impression prevails that it resists decay unusually well. In stands of larch, Douglas fir, and western yellow pine that have been killed by forest fires, it has been observed that larch remains standing after the trees of the other species have fallen.

CROSSTIES.

Nearly all of the western railroads use ties of Douglas fir, western larch, western hemlock, cedar, and redwood. As a tie timber western larch apparently gives satisfaction. The wood has sufficient strength in side bearing to withstand rail wear during its natural life. In the vicinity of Spokane, Wash., considerable larch timber is made into crossties.

FRAMING.

On account of the high percentage of common lumber in western larch most of it is used in the form of dimension material and rough boards.

When freshly cut the lumber is heavy and contains a large amount of moisture. The freight charges on shipments of green timber are high on account of its weight. Unless special care is taken in stacking, larch exhibits a tendency to warp while drying. A considerable amount of dimension larch and rough common lumber is shipped from Montana into western North Dakota.

FLOORING.

The grain in western larch is very close and the wood is firm and hard. When cut with the grain vertical it makes an excellent flooring material which wears evenly and keeps a smooth surface.

As a rule, it is somewhat difficult to cut edge-grain flooring on account of the fact that many larch logs are small. When specially ordered, however, the edge-grain flooring is furnished, but the general practice is to mix the edge and flat grain stock and sell them together.

INSIDE FINISHING.

Western larch is used as an inside finishing material in localities where it grows. It finishes smoothly and takes a high polish. It also takes stains well and, because of its hardness, does not mar

easily. The difficulty of drying is experienced also with finish material, though some mills claim excellent success with their kiln operations in the drying of inch lumber.

SIDING.

Consumers claim that the chief difficulty with larch siding is its tendency to warp when exposed.

Almost all larch knots are solid and tightly held in place, and the wood holds nails well. It is shipped into the Middle West States in carload lots where it is used for siding and roofing in the construction of freight cars.

CEILING AND MOLDING.

Larch is cut into both ceiling and molding. Some manufacturers report that they ship larch molding in carload lots as far east as New York State, and that it is very much in demand.

LATH.

Slabs and edgings of larch, fir, and western yellow pine are manufactured into lath and used indiscriminately.

APPENDIX.

TABLE 11.—*Results of bending tests of small, clear sticks of western larch.*

(2 by 2 by 30 inch beams, 28-inch span.)

Seasoning.	Number of tests.	Rings per inch.	Moisture.	Weight per cubic foot.		Fiber stress at elastic limit.	Modulus of rupture.	Modulus of elasticity.
				As tested.	Oven-dry.			
			Per cent.	*Pounds.*	*Pounds.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*
Green:								
Maximum	1	51.0	81.3	61.2	37.3	6,250	9,520	2,031
Average	189	26.2	46.2	41.8	28.6	4,274	7,251	1,310
Minimum	1	11.0	27.6	30.6	21.9	2,080	4,240	741
Seasoned:								
Maximum	1	60.0	22.2	48.9	42.1	10,350	16,180	2,328
Average	239	26.8	16.0	35.3	30.4	[1] 5,886	10,230	[1] 1,565
Minimum	1	12.0	12.0	27.5	23.2	3,215	6,830	746
Green, ratios					1.00	1.00	1.00	1.00
Seasoned, ratios					1.06	1.38	1.41	1.19

[1] Based on 235 tests.

TABLE 12.—*Results of tests in compression, parallel to grain, on clear sticks of western larch.*

(2 by 2 by 8 inch specimens.)

Seasoning.	Number of tests.	Rings per inch.	Moisture.	Weight, per cubic foot.		Compressive strength at elastic limit.	Crushing strength at maximum load.	Modulus of elasticity.
				As tested.	Oven-dry.			
			Per cent.	*Pounds.*	*Pounds.*	*Lbs. per sq. in.*	*Lbs. per sq. in.*	*1,000 lbs. per sq. in.*
Green:								
Maximum	1	60.0	90.8	62.8	40.3	4,790	5,150	3,686
Average	491	26.1	50.6	43.7	29.0	[1] 3,026	3,696	[1] 1,545
Minimum	1	11.0	28.1	28.3	18.8	1,083	2,510	798
Seasoned:								
Maximum	1	60.0	17.2	48.2	41.7	5,930	10,400	2,393
Average	268	[2] 27.2	14.8	34.8	30.3	[3] 4,174	5,937	[3] 1,630
Minimum	1	12.0	11.0	27.0	23.7	2,760	4,000	1,145
Green, ratios					1.00	1.00	1.00	1.00
Seasoned, ratios					1.04	1.38	1.61	1.06

[1] Based on 469 tests. [2] Based on 263 tests. [3] Based on 30 tests.

TABLE 13.—*Results of tests in compression, perpendicular to grain, on clear specimens of western larch.*

Group	Group, seasoning, and size of sticks.	Number of tests.	Rings per inch.	Moisture.	Weight per cubic foot. As tested.	Weight per cubic foot. Oven-dry.	Compressive strength at elastic limit.
				Per cent.	*Pounds.*	*Pounds*	*Lbs. per sq. in.*
A	Green, 8 by 16 by 24 inches and 8 by 12 by 24 inches:						
	Maximum	1	38.0	57.0	46.5	31.5	710
	Average	42	[1] 23.7	[1] 41.9	38.8	[1] 27.3	417
	Minimum	1	13.9	31.4	31.8	23.3	264
	Air-seasoned, 8 by 16 by 24 inches and 8 by 12 by 24 inches:						
	Maximum	1	30.5	22.3	42.7	36.3	718
	Average	35	22.1	18.2	35.0	29.6	509
	Minimum	1	11.5	16.0	29.3	24.7	385
B	Green, 6 by 6 by 24 inches and 4 by 4 by 16 inches:						
	Maximum	1	46.0	81.8	58.7	37.5	748
	Average	83	25.6	51.9	44.4	29.2	475
	Minimum	1	11.0	36.4	30.5	22.3	320
	Air-seasoned, 6 by 6 by 24 inches, 5 by 8 by 20 inches, and 4 by 4 by 16 inches:						
	Maximum	1	32.0	19.1	50.5	44.7	1,198
	Average	33	27.1	14.3	35.8	31.3	661
	Minimum	1	16.0	12.5	28.3	25.1	329
A and B	Green, all sizes:						
	Maximum	1	46.0	81.8	58.7	37.5	748
	Average	125	[2] 25.0	48.6	42.5	28.6	456
	Minimum	1	11.0	31.4	30.5	22.3	264
	Air-seasoned, all sizes:						
	Maximum	1	32.0	22.3	50.5	44.7	1,198
	Average	68	24.5	16.3	35.4	30.4	583
	Minimum	1	11.5	12.5	28.3	24.7	329
	Green, all sizes, ratios	....	....	....	....	1.00	1.00
	Seasoned, all sizes, ratios	....	....	....	....	1.06	1.28

[1] Based on 41 tests. [2] Based on 124 tests.

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